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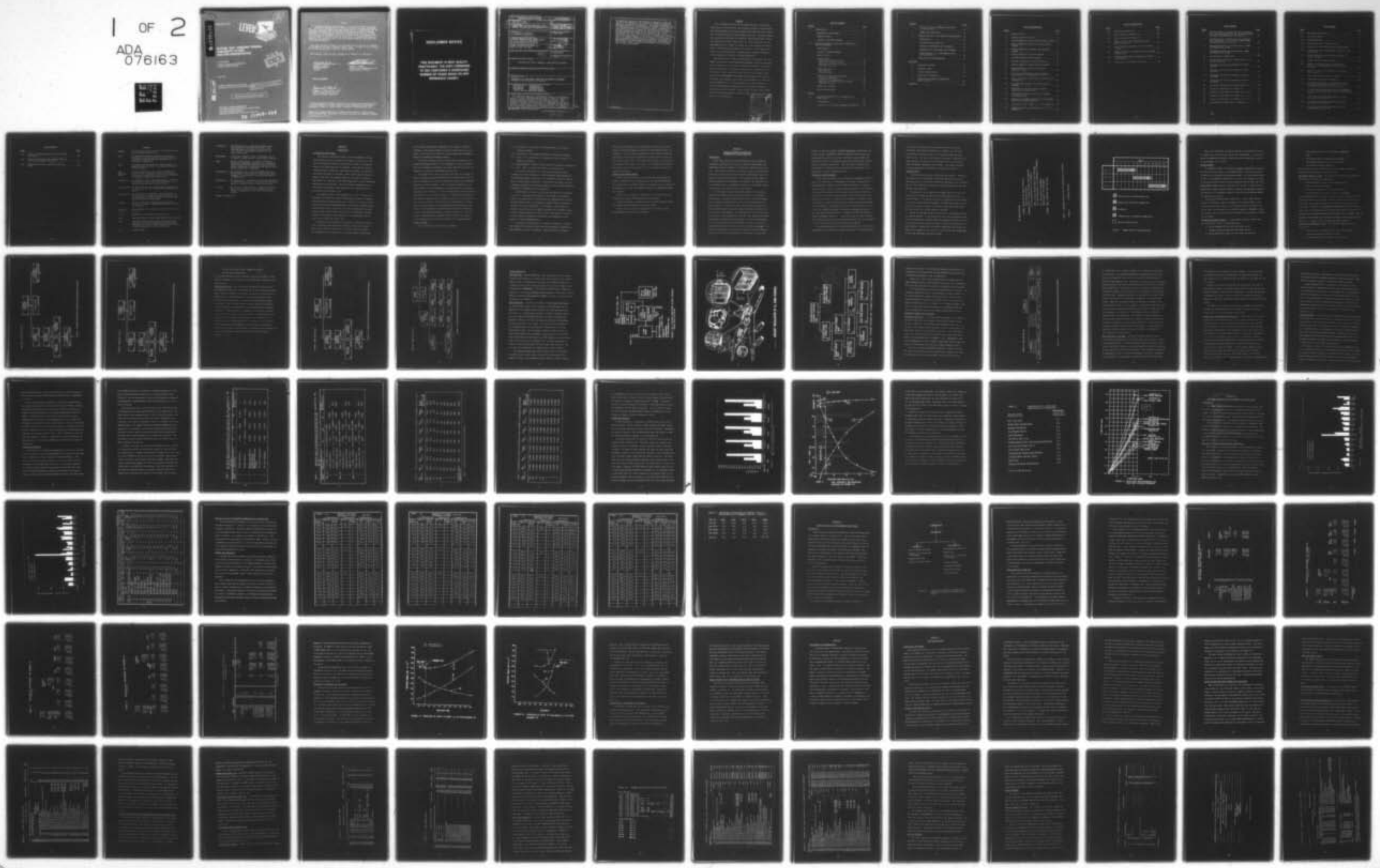

AFAL-TR-79-1105

LEVEL II

SATCOM "EHF" AIRBORNE TERMINAL AVAILABILITY TO COST ANALYSIS DEMONSTRATION

H. M. BARTMAN
AVIONIC COMMUNICATIONS BRANCH
SYSTEM AVIONICS DIVISION

JULY 1979

TECHNICAL REPORT AFAL-TR-79-1105
Final Report for the Period of July 1978 to April 1979

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This technical report has been reviewed and is approved for publication.

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A practical approach (TASA/DEPEND Program) for analyzing system "ilities" was demonstrated based on results reported in Technical Reports AFAL-TR-78-45 and AFAL-TR-78-135. This approach provides an analysis tool for studying the impact of changes in mission use on reliability, availability and dependability so that mission plans can be optimized with respect to achieving design objectives as related to cost. (continued) over

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An important feature of this analysis approach is that the impact of malfunctions and failures on system availability and cost are separately assessed. This makes it possible to directly relate the contributions of hardware module reliability and maintainability to functional block performance. Such studies provide a means for concentrating reliability and maintainability resources in areas that will provide the maximum system improvement at the minimum cost. Also, a relational basis for trade-offs between reliability and maintainability requirements is obtained in relationship to cost. Thus, the DEPEND PROGRAM can be a valuable tool for management of reliability/maintainability programs, development of requirements for procurement specifications, evaluations of the "ility" impact of engineering changes and the assessment of testing programs.

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FOREWORD

This "IN-HOUSE" Technical Report, AFAL-TR-79-1105, describes and demonstrates the various tools and procedures available to the designers and program managers for avionic systems design trade-off of key factors such as system reliability, maintainability and cost. The work reported was accomplished under Work Unit 12270313, "SATCOM FLIGHT TEST", during the period of July 1978 to April 1979. Mr. Allen Johnson was the Program Manager and Mr. Herbert M. Bartman the Project Engineer for Reliability. The author also presented this report as a case study to the Faculty of the Graduate School of Engineering in partial fulfillment of the requirements of ENM 566, "ADVANCED RELIABILITY."

The author wishes to express appreciation to his advisor, Dr. John Fraker, the Director of the Engineering Management Program of the University of Dayton, for his interest and supportive guidance in the preparation of this report. The author's appreciation is extended also to Mr. Thomas S. Cuff of the ASD Computer Center for his support in providing various TASA/DEPEND Program ANALYSIS RUNS during the course of this study, and to Messrs. Joseph Simon and Tim Humphrey and the typing staff of SYSTRAN Corp. for the preparation of the final manuscript. A special acknowledgement is made here for the referenced sources not specifically cited in the text. These sources provided excellent background in the understanding of the subject under study and in the preparation of this manuscript.

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GLOSSARY

Assembly	The functional block at levels of the functional hierarchy above the elemental level.
ATBO	The Average Time Between Occurrences of a specified malfunction or failure state for an assembly based on an assumption that the time distribution of their occurrences is exponential.
ATTR	The Average Time To Restore the assembly function to normal following occurrence of a specified malfunction or failure state.
ATTR Weighting Factor	A factor ranging from 0 to 1 used to determine the time to restore an assembly's function following the occurrence of a combination of two or three subassembly or element malfunction and failure states.
Availability	The probability that a specified assembly is functional at the start of each of the specified number of uses during the specified mission time interval.
Average Delay	The delay that the user can expect when a malfunction or failure occurs. (Also called Average Nonoperational Delay.)
Dependability	The probability of completing a specified number of functional cycles during a specified interval of time of an assembly (or element) without experiencing a malfunction or failure induced delay.
Element	The basic functional building block in the system functional hierarchy. The MTBF and MTTR data are input at this level.
Functional Cycle	The performing of an assembly's function from start to finish.
"ility"	dependability, availability and reliability
MTBF	Mean Time Between Failures or malfunctions for an element.
MTTR	Mean Time To Restore an element's function by repair, replacement or other means following occurrence of a malfunction or failure. MTTR includes the time needed to detect malfunction or failure occurrence.
P.C.	Printed Circuit

Reliability	The probability that a specified assembly successfully performs its function during each of the specified number of functional cycles given that it is capable of performing its function at the start of each cycle.
Subassembly	A functional assembly becomes a subassembly when it it used at a higher level of the functional hierarchy.
TASA	Tabular System Analysis: An orderly procedure for developing a functional organization of a system, defining the malfunction and failure states and recording the consequences of malfunction and failure occurrences, singly and in combination.
Unavailability	The probability that a specified assembly will not become capable of performing its function when needed because of the occurrence of a specified malfunction or failure state.
Unreliability	The probability of occurrence of a specified malfunction or failure state during one (or more) of the specified number of functional cycles of specified duration.
Use Time	The interval of time required to complete a specified number of functional cycles not counting any time between the completion of one cycle and the start of the next.

SOURCE: AFAL-TR-78-135

SECTION I

INTRODUCTION

DEFINITION OF THE PROBLEM

The worth of a particular system or piece of equipment is determined primarily by the effectiveness with which it does its job. Emphasis on equipment reliability alone does not result in the required level of cost and operational effectiveness. Other factors, such as system performance capability, operational reliability, tactical availability and cost must be considered. These factors can be defined in terms of "how well" the equipment operates, "how long" it operates, "how often" it is available, and "how economically" it can be developed, manufactured, and maintained. Thus, effectiveness (dependability) is the product of reliability and availability for a specified level of performance and a particular cost.

One important aspect of any equipment is its cost. Usually, the development and design of systems and equipment are made to a required specification at a minimum initial cost. However, an initial cost consideration neglects maintenance expense of keeping the equipment working satisfactorily while in the field. The cost of maintenance and repair depends greatly on the initial reliability of the equipment, the more reliable an equipment the less costly will be the maintenance and repair, but the higher the initial cost.

In virtually every program it is necessary to keep within certain budget constraints, and the available funding obviously has a major impact on the technical capability of the system under development. Cost information is an integral part of decision making (particularly

cost to system effectiveness trade-off) in all stages of system development. Thus, greater emphasis is given system design to cost instead of life cycle costs during the initial concept and development phases of an advanced development program.

This report describes the tools and procedures available to the designer and program manager in the development of avionic systems as aids in the trade-off requirements and assets among the key factors of capability, reliability, maintainability, and cost.

The problem in this study is to bring into focus the findings reported in Technical Reports AFAL-TR-78-45 [3] and AFAL-TR-135 [14], in order to demonstrate the possible approach by applying the TASA/DEPEND program to an ongoing program. This will provide guidelines to the system designer and program manager for design approaches, processes, methodology, and techniques to achieve desired SATCOM system reliability/availability in a cost-effective manner. A reliability/availability to cost trade-off approach will be discussed, and it will be based on baseline costs as related to system reliability, maintainability, availability, and dependability for the Ka-Band SATCOM Set reported in Reference 14. This approach will demonstrate the means for determining the major subassembly contributor of system unreliability. This will result in addressing those equipments which contribute the greatest system undependability based on an assumed level of maintainability.

METHOD OF ATTACK

This paper addresses the following parameters:

(1.) Availability: Probability of being available to send and/or receive a message.

(2.) Reliability: Conditional probability of completing a message.

(3.) Delay: If not available, or a malfunction, what the delay is in completing a message.

(4.) Maintainability: Time to restore operation, degraded or inoperative.

(5.) Cost: Effect of above requirements on acquistion costs.

The technical approach uses a Tabular System Analysis (TASA) technique to provide estimates of system reliability and availability for alternative modes of operation. The techniques include the development of a system model organized in a functional relationship form and a computer program which calculates estimates of three related quantities reliability, dependability, and availability.

In addition, the results of sensitivity calculations are presented in terms of a percentage contribution of each element or subassembly state to its unavailability, unreliability and undependability for each defined assembly state. This provides a rational basis for allocating resources to achieve improvements. Also, PRICE, a computerized cost estimation program was used for making reasonable cost estimates. Thus, Battelle Columbus Laboratories (BCL), as part of Reference 14, reported on three complete reliability, availability, and dependability TASA analyses of the Ka-Band SATCOM Set.

In performing a TASA analysis, the system or equipment is divided into a number of functional blocks, and the dependability, availability and reliability of each is estimated. These are based on a defined

mission the user desires to be accomplished in terms of user's perception of system performance, reliability, maintainability and cost estimates. In this study, a hypothetical 10 hour mission profile was established, as discussed in Appendix A specifying 240-five line forward link messages, 720-two line report-back messages, and three hours of conference links usage. All results are expressed as the degree of satisfaction the user could expect if he were involved in flying the hypothetical mission.

PREVIEW OF THE REPORT CONTENT

Section II briefly brings into focus the data and findings reported in reference 14 as an application of the TASA/DEPEND Program in a follow on to the system reliability assessment given in reference 3. In appendices A, B, and C the DEPEND Program and the TASRA/TASA Models are discussed.

Section III and Appendix D demonstrates the procedures for computing the percentage contribution analysis capability.

Section IV presents a trade-off analysis and the supporting Appendix E demonstrates the minimum cost decision model.

Section V gives the major conclusions of the report and some recommendations for further considerations.

SECTION II

SYSTEM AVAILABILITY, RELIABILITY, DEPENDABILITY AND COST ESTIMATES

INTRODUCTION

Design teams involved in the development of major systems are continually confronted with the need to trade-off requirements and assets among the key parameters of reliability, maintainability, and cost. This problem is faced in the earliest stages of system concept and design, and continues through the various development phases virtually to the point of production. (The problems actually persist through production and throughout the lifetime of the equipment, but at a different level of consideration because of the inherent limitations placed on the options at these later stages.)

It is during the various development phases that the greatest payoff can be achieved through careful allocation of requirements and resources. The degree these decisions can be controlled depends on how complete the program plans are at the very beginning of the system concept. If such is the case, then reliability growth can be well tracked and controlled, and an early definition of specific objectives can be made and met. But frequently the "ility" efforts and even realistic cost considerations come into play somewhat later after the system is already pretty well-defined. Then the problem becomes one of setting reliability and maintainability goals to achieve the desired objectives of the system within an acceptable <u>cost range</u>. Frequently the objectives are not clear and have not been truly derived from the overall mission requirements of the system. The key then

becomes not only one of how to establish appropriate requirements and perform rigorous, meaningful trade-off analyses between reliability, maintainability, and cost, but also clarifying the goals after the project has reached the breadboard stages and establishing the methodology for obtaining these goals. Thus, this report discusses such an approach for assessing system reliability and availability in relationship to system performance and cost.

APPROACH TO SYSTEM ESTIMATES

One of the initial goals of the computations performed in this report is the generation of availability, reliability, maintainability and dependability estimates of the Ka-Band SATCOM Set for a typical tactical mission. Before estimates could be prepared, it was necessary to determine the duration of this typical mission, and to establish the extent to which the various functions of the system would be used during such a mission. In short, it was necessary to establish a mission profile. Further, after the mission profile had been established, it was necessary to incorporate this into the analytical model in such a way that effective use could be made of the information, while at the same time allowing flexibility. Changing tactical requirements or modified equipment capabilities could easily alter the mission profile. The following describes the mission hypothesized for the system estimates in this report and as given in reference 14 by Battelle.

The actual estimates of the interrelated quantities of reliability, dependability, and availability were obtained, with the DEPEND program,

in a series of calculations that provided values for all three essentially simultaneously (Appendix A). However, cost estimates are addressed separately, based on the RCA/PRICE MODEL applied by Battelle [14]. The first three items are presented in sequential sections following the mission profile discussion, but are discussed from a conceptual viewpoint in this section. The reader interested in a more mathematical presentation is referred to Appendix B.

MISSION PROFILE

A typical mission duration of ten hours was selected (Figure 1). This is based on an eight hours "on-station" period plus an hour of operation prior to and an hour of operation subsequent to the on-station period. These additional two hours are used for system start-up, data transfer, and shut-down.

To illustrate, let us suppose that Command Posts A, B, and C are to provide the command function for one twenty-four hour period, as shown in Figure 2. During the first hour of operation CP-B will accomplish system initialization and checkout, and will accept data from CP-A which is currently on-station. These data include any messages that, for any reason, CP-A has been unable to transmit.

During the following eight hours CP-B will be on-station providing the command function. In the last hour of this eight hour period, CP-8 will also transfer any necessary data and untransmitted messages to CP-C. At the end of the eight hours CP-C comes on-station, providing the command function. Finally, CP-B will have an additional hour in which to complete the transfer of data to CP-C if this has not been accomplished, to shut down equipment, and return to base.

10 HOUR MISSION

1-HOUR, START-UP AND DATA TRANSFER,
AND INITIALIZATION

8-HOURS, 240 - 5-LINE FORWARD LINK MESSAGES
5 x 40 CHARACTERS x 4.2 SECONDS

720 - 2-LINE REPORT-BACK LINK MESSAGES
2 x (40 CHARACTERS x 4.2 SECONDS) + PREAMBLE

12 - 15-MINUTE CONFERENCES
(214 LINES x 4.2 SECONDS)

1-HOUR DATA TRANSFER AND SHUTDOWN

NOTE: 1 Message Defined as 200 Characters (33 Words)

Figure 1 MISSION PROFILE

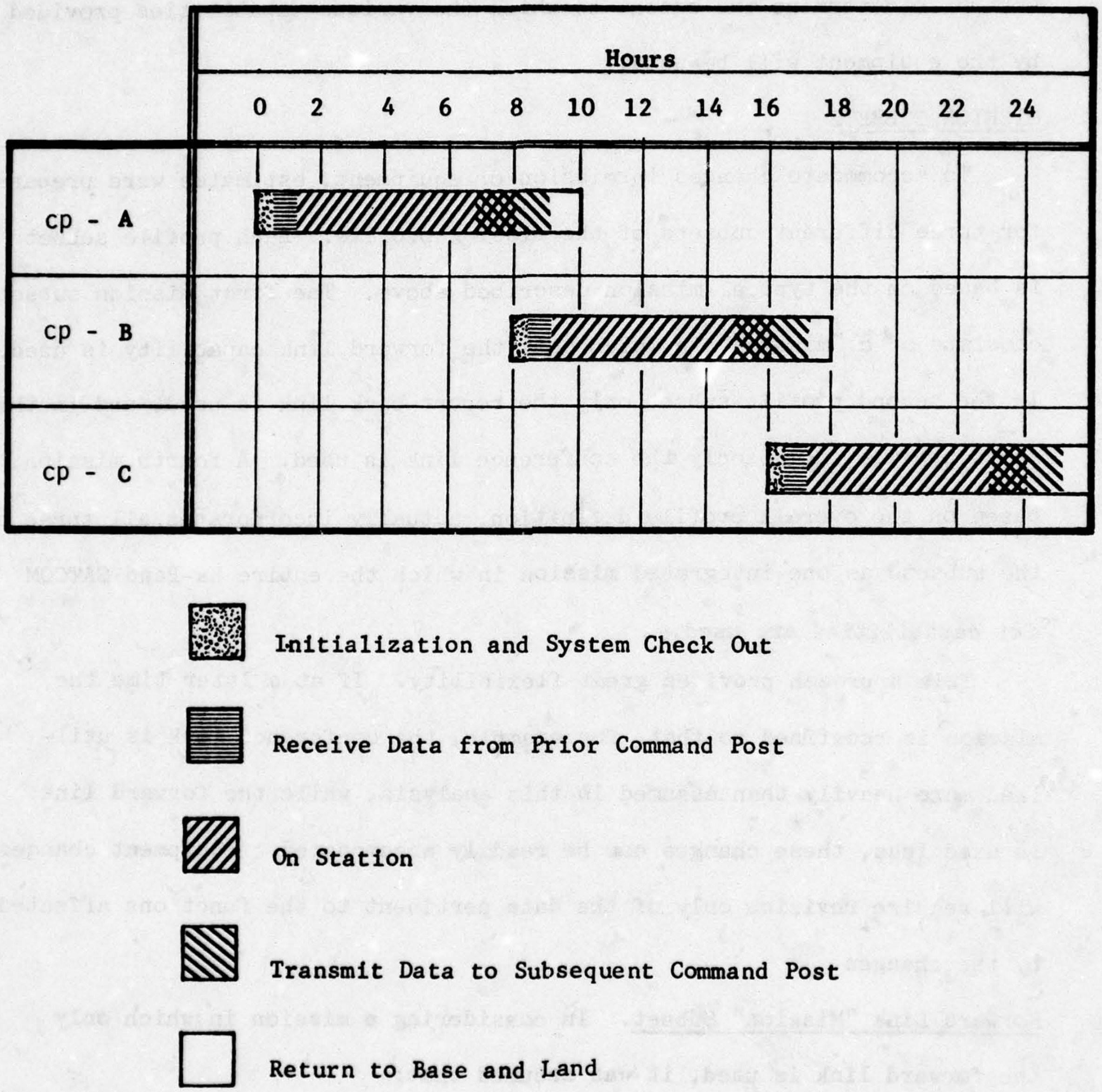

FIGURE 2. COMMAND POST (CP) MISSION OUTLINE

This, then, represents the general outline of a hypothetical mission. To complete the mission profile required for computations, it is also necessary to determine the extent to which the various capabilities provided by the equipment will be used.

MISSION SUBSETS

To accomodate changes in mission or equipment, estimates were prepared for three different subsets of the mission profile. Each profile subset is based on the typical mission described above. The first mission subset consists of a "mission" in which only the forward link capability is used. In the second profile subset only the report-back link is used, and in the third profile subset only the conference link is used. A fourth mission, based on the overall profile definition, actually incorporates all three of the subsets as one integrated mission in which the entire Ka-Band SATCOM Set capabilities are used.

This approach provides great flexibility. If at a later time the mission is redefined so that, for example, the conference link is utilized more heavily than assumed in this analysis, while the forward link is used less, these changes can be readily accomodated. Equipment changes will require revision only of the data pertinent to the functions affected by the changes.

Forward Link "Mission" Subset. In considering a mission in which only the forward link is used, it was assumed that:

1. Thirty messages would be sent every hour, on the average, during the eight hour on station period.
2. Each message would consist of five lines, and each line

would require one cycle of 4.2 seconds transmission time.

3. Verification would be concurrent with message transmission, except for a 4.2 second offset. See Functional Diagram, Figure 3.

These figures result in a mission in which 240 messages, consisting of a total of 1200 transmission cycles, are sent.

Report-Back "Mission" Subset. The mission in which only the report-back link is used is defined as consisting of:

1. Ninety messages per hour, on the average, for the eight hour on-station period.

2. Two lines per message, at 6.3 seconds per line. The additional time per line is used for a preamble.

Thus the report-back link mission includes a total of 720 messages of two lines, each requiring 6.3 seconds. Special consideration must be given to the fact that numerous portions of the system are common to two or three links. Therefore, in apportioning reliability, MTTRs, etc. among these links it is convenient, for computational purposes, to divide the operation of the various functions into increments of 4.2 seconds. The 720 messages received during the report-back-link-only mission represent 2160 cycles of 4.2 seconds each. See Functional Diagram Figure 4.

Conference Link "Mission" Subset. The conference-link-only mission consists of:

1. Fifteen minutes of conference per hour, on the average, during the eight-hour on-station period.

2. An additional hour of conference link activity, to

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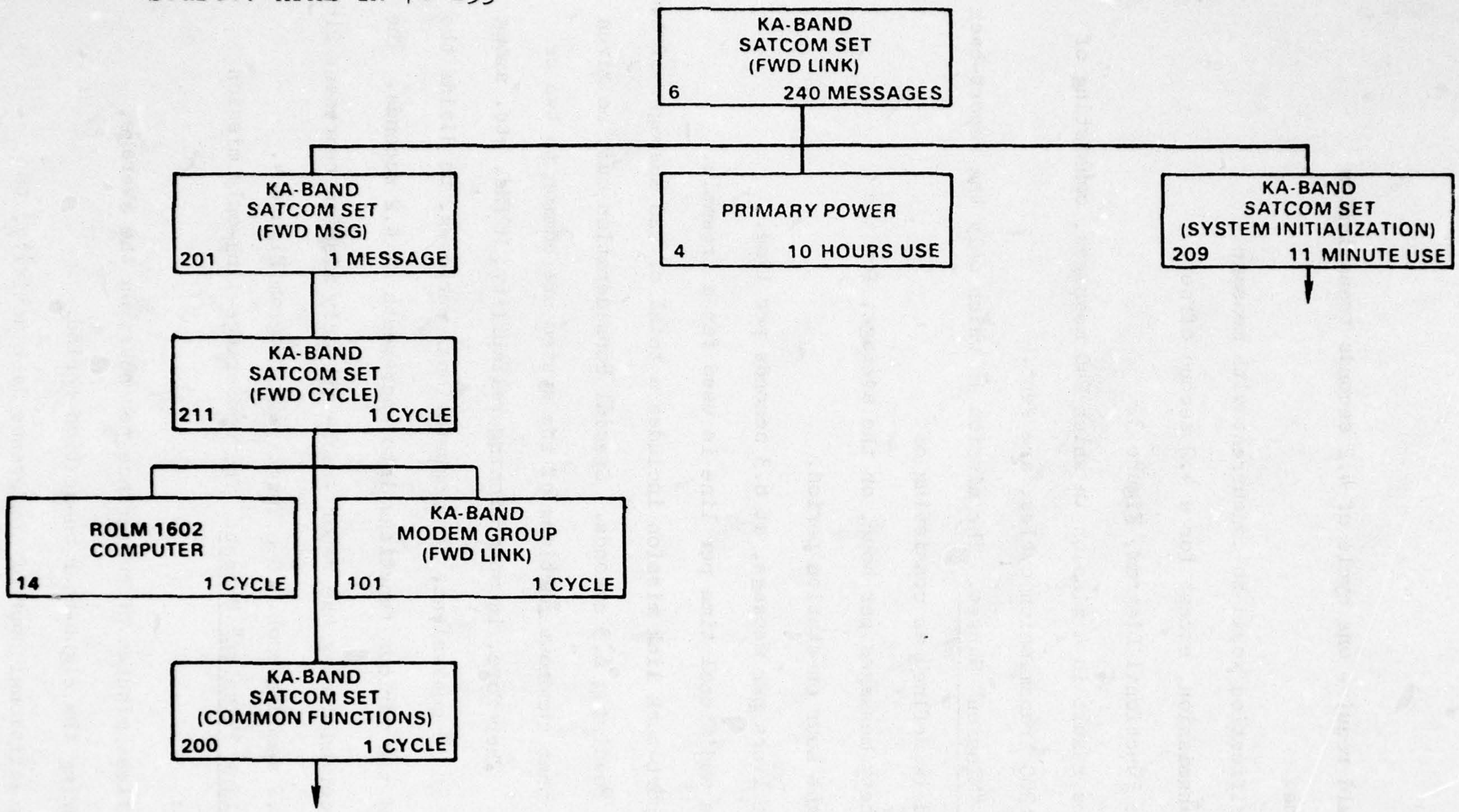

FIGURE 3. KA-BAND SATCOM SET FORWARD LINK FUNCTIONAL DIAGRAM

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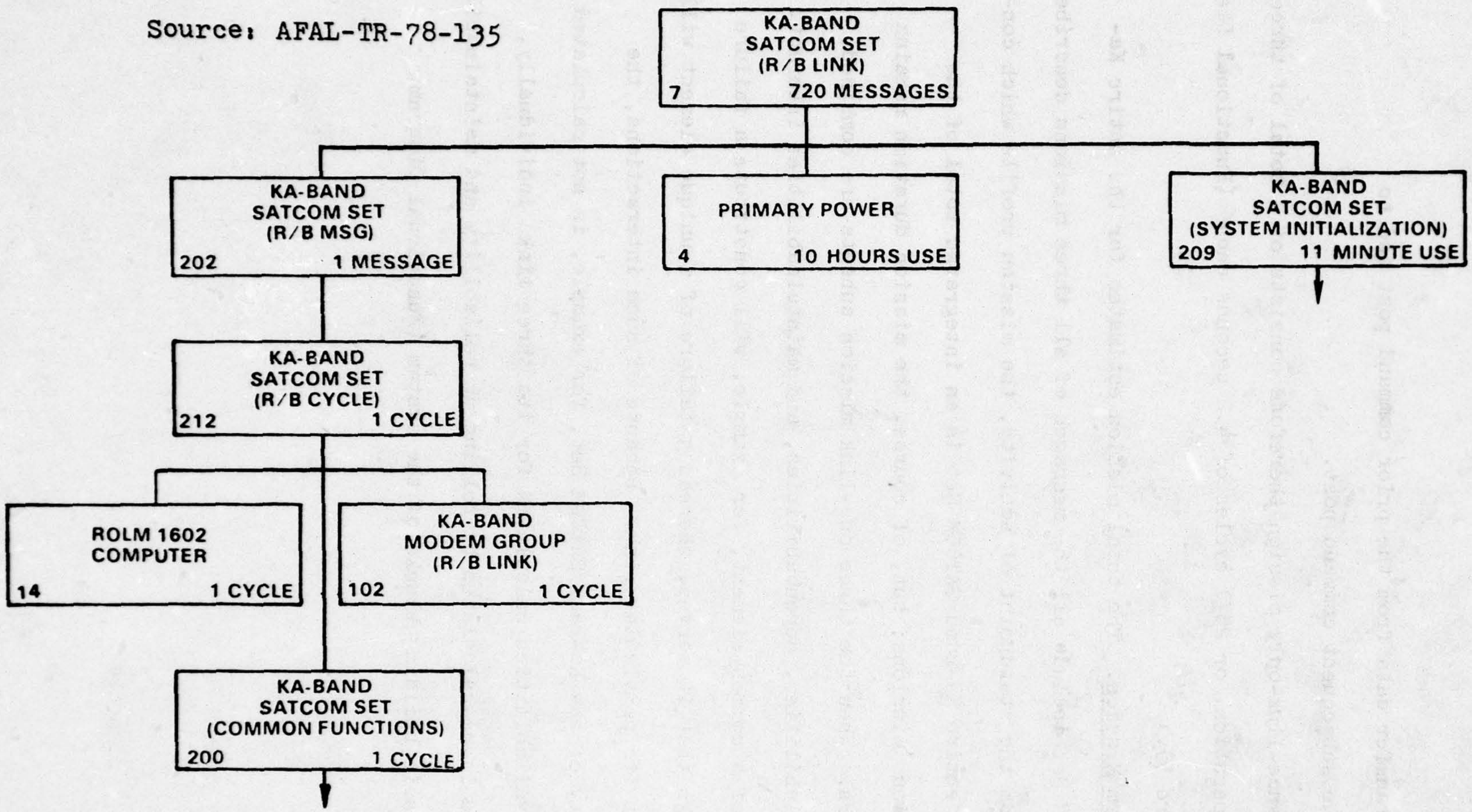

FIGURE 4. KA-BAND SATCOM SET REPORT-BACK LINK FUNCTIONAL DIAGRAM

transfer data from the prior command post and to the subsequent command post.

The conference-link-only mission therefore consists of a total of three hours of operation, or 2571 cycles of 4.2 seconds each (Functional Diagram, Figure 5).

Total System Mission. The total mission estimates for the entire Ka-Band SATCOM Set include all the messages of all three missions described above. From the standpoint of activity, the mission profile which considers the entire Ka-Band SATCOM Set is an integrated total of the three previous missions; but, of course, the mission duration remains at ten hours. When the three one-link mission subsets are combined, their availabilities, dependabilities, and maintainabilities interact. A failure of a common element, for example, will constitute a failure of all links that it serves, whereas a failure of a unique element will only affect its particular link. Because of such interactions, the availability of the Ka-Band SATCOM Set, for example, is not calculated from the availabilities calculated for its three links individually, but instead is re-calculated by rolling up reliability and maintainability from the basic building blocks of the system (Functional Diagram, Figure 6).

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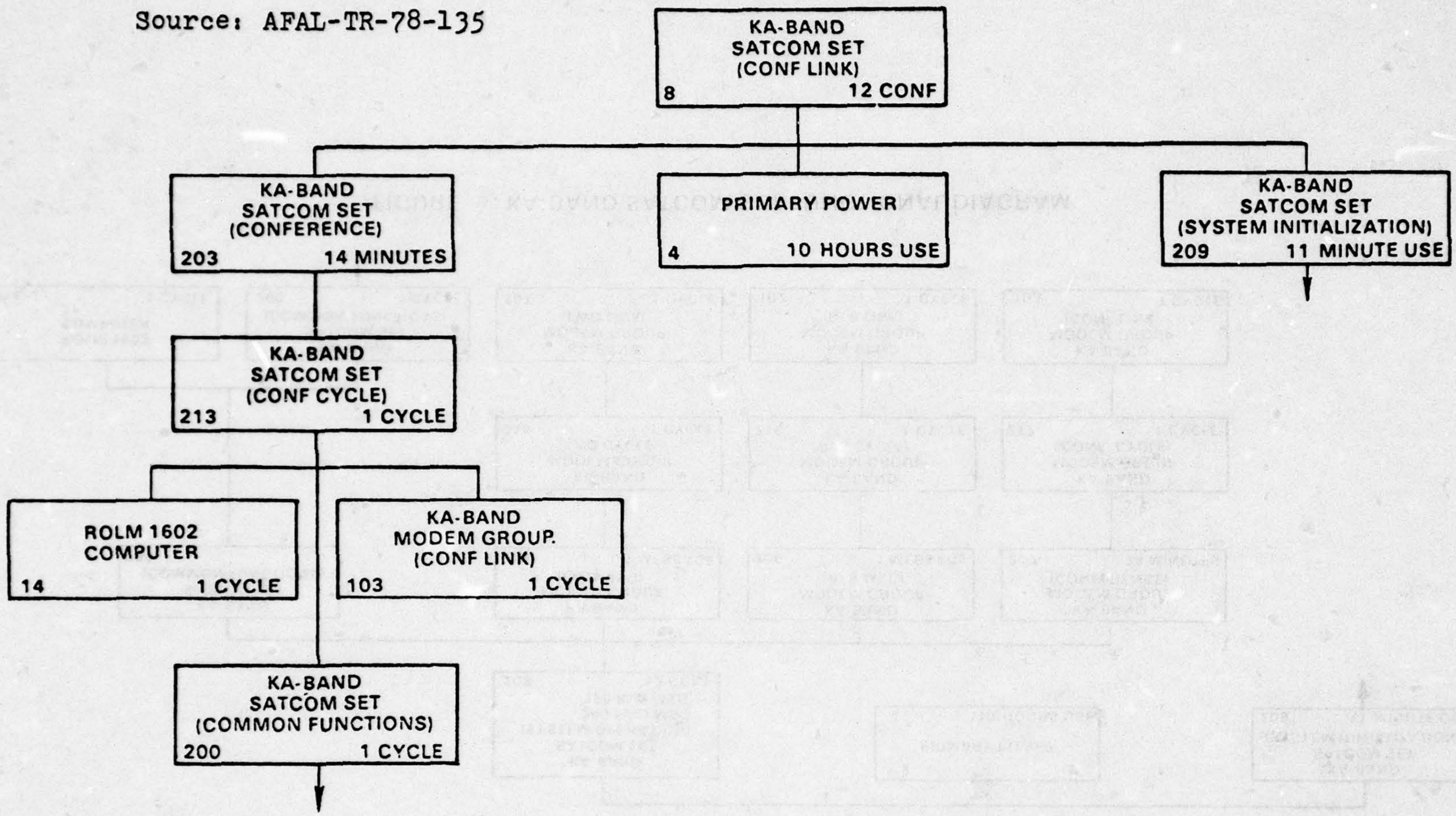

FIGURE 5. KA-BAND SATCOM SET CONFERENCE LINK FUNCTIONAL DIAGRAM

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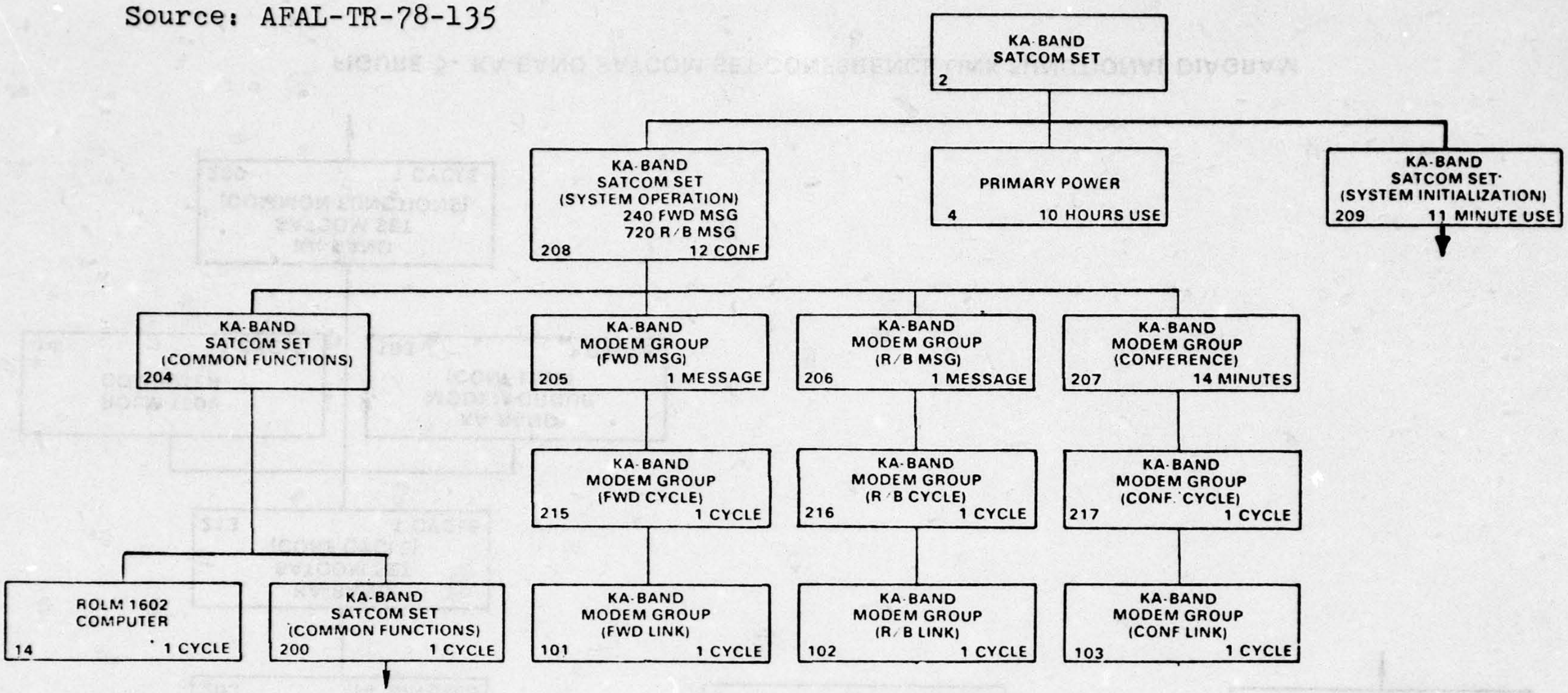

FIGURE 6. KA-BAND SATCOM SET FUNCTIONAL DIAGRAM

SYSTEM DESCRIPTION

EHF SATCOM SET. The EHF SATCOM Set, under consideration in this demonstration, was installed in a 4950th Flight Test Wing C-135 test aircraft (Tail Nr. 662). A simplified block design of the SATCOM hardware and a pictorial view of the aircraft installation are shown in Figures 7 and 8 respectively (Reference 1). The airborne SATCOM Terminal (AN/ASC-22) consists of a 1000 watt millimeter wave transmitter, a low noise receiving system, a modulator and demodulator (MODEM), and input and output devices, as discussed in reference 3.

PREDICTION MODEL. The prediction model for the Ka-Band SATCOM System is organized with respect to the functions to be performed; that is, communication by forward link, conference link, and report-back link. In addition to the individual functions of forward, conference and report-back links of the Ka-Band Set there have been identified three "common" functions; these are, functional groupings of the equipment that influence two or three links. The common function includes all of the hardware that can cause failure or degradation of all three communication links. The forward and conference common function includes the hardware that can degrade or cause failure of these links without affecting the report-back link. The conference and report-back common function includes the hardware that can cause degradation or failure of these links without affecting forward link operation. The functional tree diagram of this organization is shown in Figure 9.

Each hardware element and element grouping used in the analysis is identified by a numeric index. Each box in the functional tree diagram in Figure 3 and subsequent figures includes a numeric index in

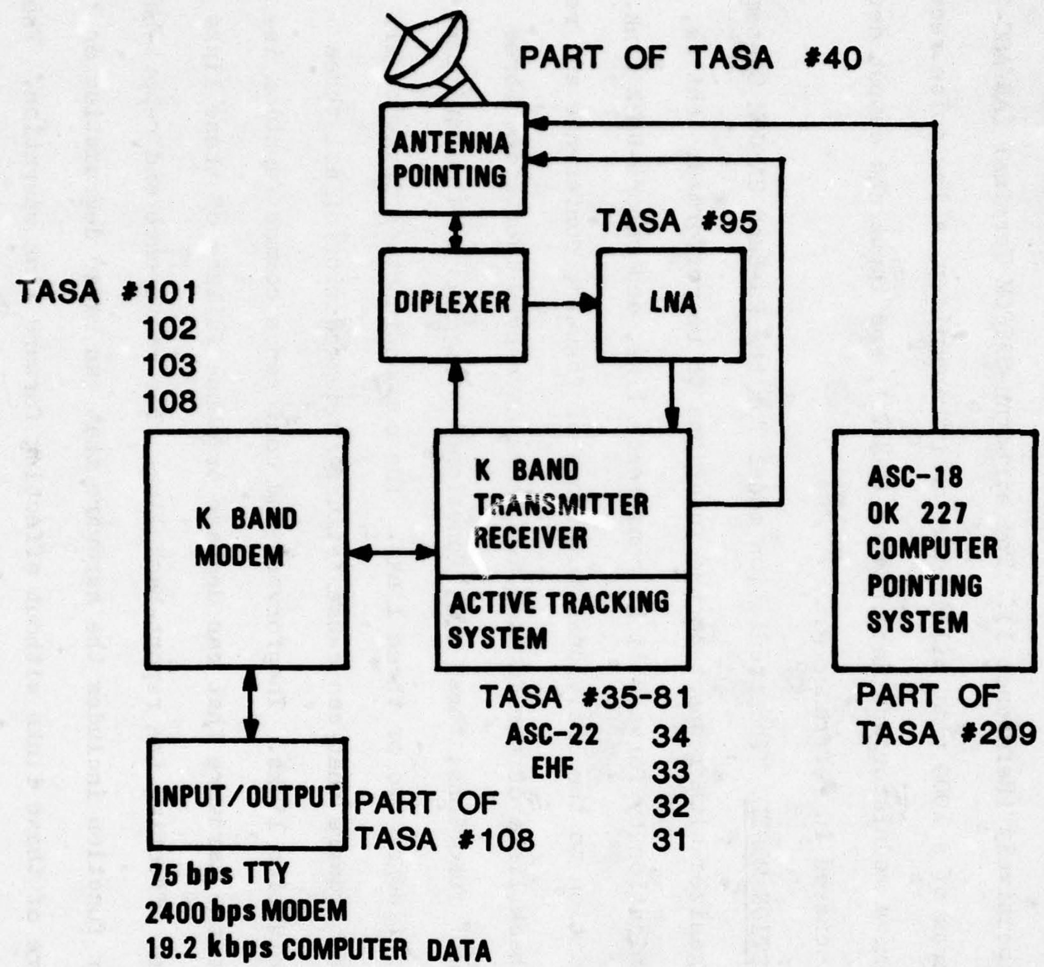

FIGURE 7 AC C135/662 SIMPLIFIED BLOCK DIAGRAM
FROM AFAL-TR-78-45

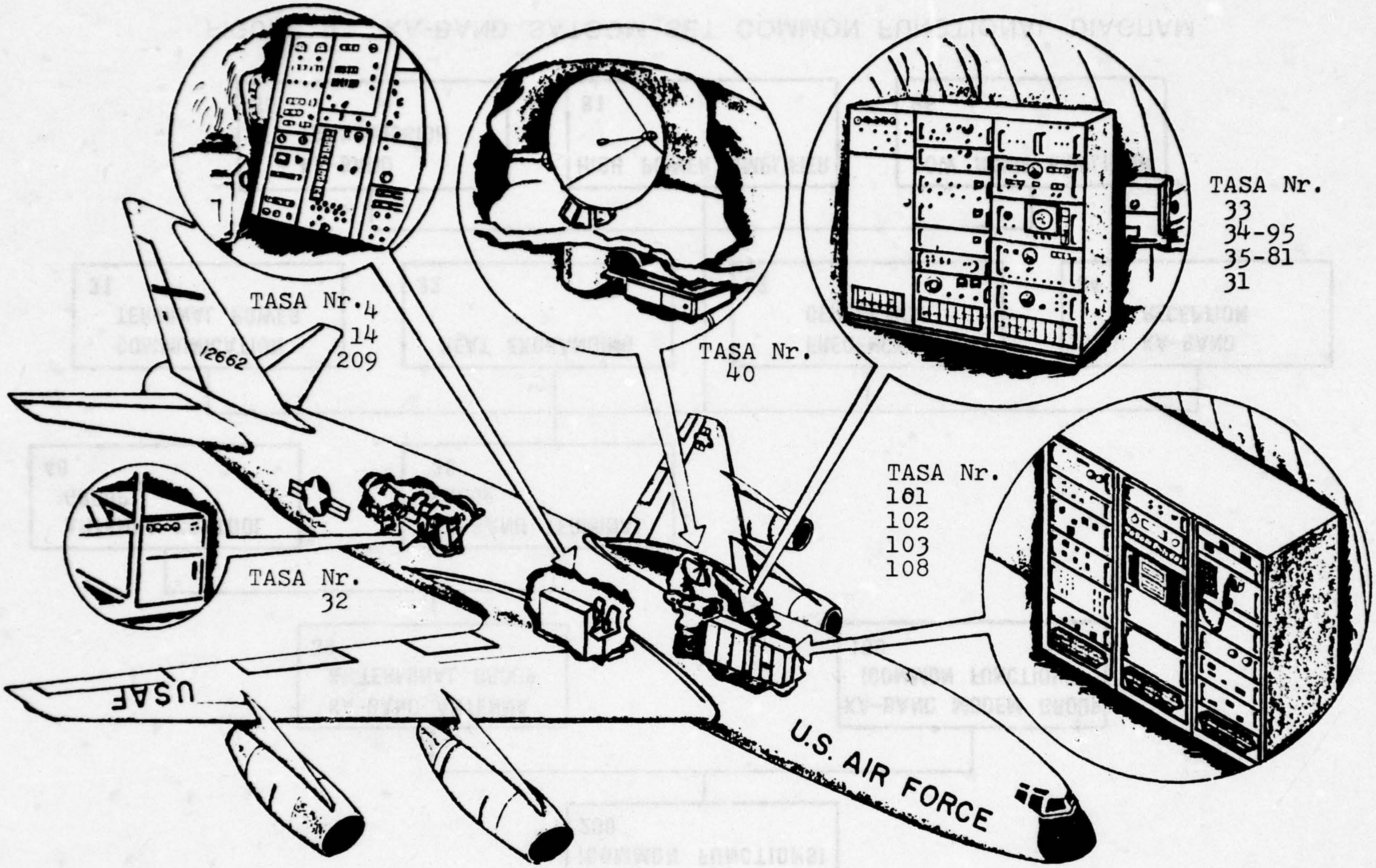

Figure 8. **AIRCRAFT INSTALLATION OF K_A BAND-TERMINAL**

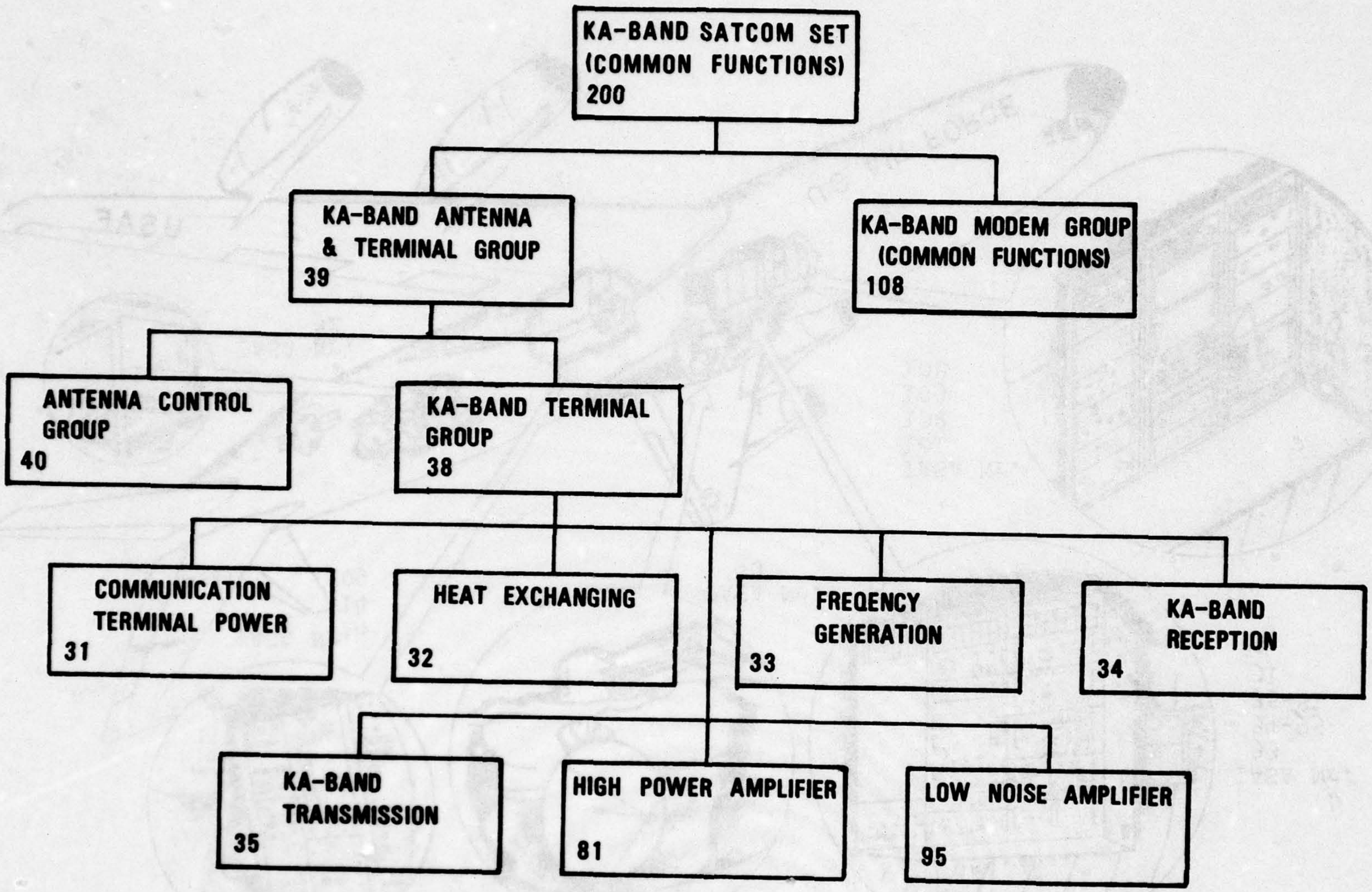

FIGURE 9. KA-BAND SATCOM SET COMMON FUNCTIONAL DIAGRAM

the lower left corner. The element and grouping identification corresponding to each index number used are tabulated together with the corresponding malfunction states in Appendix A.

Figures 3, 4, and 5 show the functional tree diagrams for the SATCOM Terminal forward, report-back and conference link, respectively. Both individual and common functions of the Ka-Band Set are included.

Prior to operating the system, an initialization is necessary. The functional diagram relating to initialization is shown in Figure 10. The Ka-Band SATCOM Set common functions as shown in Figure 9 are a truncated version of that shown in Figures 10, 11, 12, 13, and 14 of Report AFAL-TR-78-135, Part I, Volume I [14]. From the hardware viewpoint, the two major equipment groupings of the Ka-Band SATCOM Set are the Ka-Band Modem Group and the Communications Terminal Group.

ESTIMATING CONCEPTS AND PROCEDURES

Reliability Estimates. The reliability (R) estimates for the ADM system under study have been prepared, using the TASA (Tabular System Analysis) technique. This technique can accommodate failures, i.e., conditions that prevent system operation, as well as malfunctions, in which only a portion of the system is inoperative. If a malfunction occurs, the system may operate at a reduced power output with fewer options as to operating mode or frequency, etc.. Nevertheless, some form of communication will be possible. Thus, TASA simulates real conditions more accurately than many other system reliability models.

Prediction of system performance using TASA is made by dividing the system into functional blocks as described in reference 14. This was accomplished for the existing (ADM) system by obtaining lists

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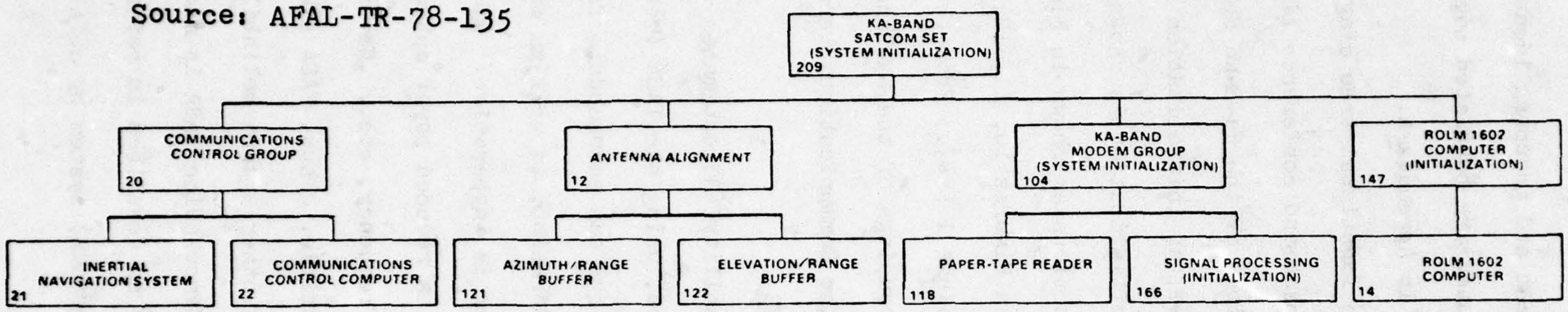

Figure 10. KA-BAND SATCOM SET SYSTEM INITIALIZATION FUNCTIONAL DIAGRAM

of "black boxes" (i.e., chassis, drawers, p.c. boards, etc.) that make up the system. The equipment manufacturers cooperated in providing reliability estimates for each black box, usually calculated using the methods of MIL-HDBK-217B [23]. The effects of failure of each black box on system performance were then evaluated, again with the help of the equipment manufacturers. The black boxes serve as the basic building blocks (functional elements) of the system as it is "assembled" in the computerized TASA model. Engineering analysis of the results of the above steps yields a tabulation of the functional contribution of each functional element comprising the Ka-Band SATCOM Set and makes it possible to assign reliability values to these elements. The possible functional states of each element, including the various modes in which it might fail and the consequences of failure (i.e. catastrophic or any of a number of degraded modes), are determined. The "ilities" of the functional elements are then combined to obtain the "ilities" of larger functional entities and ultimately the entire Ka-Band SATCOM Set, as described in the subsequent Estimate Roll-Up Section of this report. A discussion of the derivation of this technique is given in Part III of reference 14 and in Appendix A of this report.

<ins>Maintainability Predictions</ins>. The basic functional elements used in the reliability predictions, as described above, are also used to predict system maintainability. The maintainability predictions require information on the MTTR, (mean time to restore) needed to restore the operation of any element after a failure has occurred. Only maintenance that would be performed in flight, or while the equipment is in use, is considered in this analysis. In some cases, an alternative mode of operation may

be selected which circumvents the failed element. If this represents a satisfactory method for transmitting or receiving the message, the time to establish this alternative mode of operation is the MTTR used for that element.

Realistic estimates of the average mean restoration time (ATTR) of the system was based on information sought from the technicians who performed maintenance on the existing ADM hardware. This data was reported in reference 14 by BCL. From this source of information the MTTR for failures in each basic functional building block in the system was established.

The MTTRs of the functional elements are accummulated in order to determine the ATTRs (average time to restore) of larger functional entities and of the entire Ka-Band SATCOM system.

Availability and Dependability Estimates. Availability (A) is the probability that a specified function is in its normal operating state at a specified time, or that an acceptable alternative mode of operation can be provided. If the user decides that he wants to send a message immediately, availability is the probability that he will find the Ka-Band SATCOM Set in an operational condition at that time. Availability is a function of equipment reliability or its average time between failures or malfunctions (ATBO) and the average time needed to restore the equipment to normal operation or to provide an alternative acceptable mode of operation (ATTR). If the equipment exhibits a long ATBO and a short ATTR, the probability of finding it in the normal operational state will be high. On the other hand, if its ATBO is short, and its ATTR is high, we would expect to find it in a nonoperating

state much of the time. Availability is also a function of mission duration and number of messages anticipated during the mission. These factors determine the amount of standby time between messages.

System dependability (D) is defined as the probability that a specified number of communications can be begun and completed without a system malfunction or failure. The dependability is the probability that all the communications required for a specified mission duration will be completed without an equipment failure that results in a delay. Thus, associated with the dependability prediction is an estimate of communication delay which gives the average length of delay attributable to equipment failure that the user may expect if a failure or malfunction occurs.

Estimate Roll-Ups. As noted earlier, although reliability, dependability, and availability have been discussed in a sequential order, the computer program used actually calculates all three of these quantities at essentially the same time. As discussed by Drennan of Battalle in reference 14, the SATCOM SET was first divided into a number of "black boxes", or basic functional building blocks (elements). Reliability figures for each element were established (data from equipment manufacturers), and the mean restoration time (MTTR) of the system for specified failures or malfunctions of each element was established.

The computer calculates the availability (A) and dependability (D) of each functional element. It then combines these data for the elements into larger functional assemblies and combines these, in turn, into still larger assemblies, continuing this process until the last functional assembly of SATCOM Set is reached. At each level and for each functional

block the availability, reliability, dependability, and maintainability are calculated, using the TASA approach briefly discussed in Appendices A, B, and C.

There is one additional consideration required for maintainability, since weighted averages are used rather than simple arithmetic averages. As the maintainabilities are calculated for the larger functional assemblies, they are expressed as the weighted average restoration time (ATTR). The ATTR differs from the MTTR in that the ATTR includes weighting factors relating to the dependabilities of the various basic building blocks comprising the particular function. Thus, in calculating the ATTR of the higher level functional assemblies, the MTTRs of the elements are weighted according to their dependabilities (the probabilities that they will require a repair action). This is necessary so that the ATTRs may represent a realistic average time to restore operation of a major function or of the entire SATCOM Set, as discussed by Drennan in reference 14.

SYSTEM "ARD" ESTIMATES

In performing the availability/dependability, reliability, and maintainability analyses for the Ka-Band SATCOM Set, estimates were generated based on functional elements composed of specified hardware. These were then rolled up to obtain estimates of the three major functional assemblies or links comprising the system. At this level, estimates for different mission profiles were prepared and combined until estimates for the entire Ka-Band SATCOM Set were obtained for a typical mission. Table 1 lists the Ka-Band SATCOM Set and its functional states

for RUN ONE and provides the appropriate estimates generated for them. Table 2 provides estimates generated for the three mission subsets (RUN ONE). For each malfunction or failure mode, values for availability/dependability, maintainability (mean time to restore), and reliability are given.

The availability values listed in Tables 1 and 2 for RUN ONE give the probability that the Ka-Band SATCOM Set will be operational at the time the user of the equipment needs to send or receive a message, provided that the particular functional state that is identified can be tolerated. The concept of availability allows for inclusion of the possibility that if, for example, the mode of message transmission first selected is not functional, an alternative transmission mode could be selected; so that a means of message transmission may be immediately available even if the equipment were not completely operational. The bar graphs in Figure 11 give availability values at selected levels of MTBF for Elements E35 and E81.

In Table 3 and Table 4, RUNS ONE through SEVEN show that the MTBF for Elements E35 and E81 was varied from a base of 1.0 to three times the original value. However, in RUN EIGHT, the MTBF was set to the base value and the MTTR was set to one hour for E35 and E81. Expected malfunction values are listed for the designated element, subassembly, assembly, subsystem and system. The ATBO is also given for Assembly 38, showing that as the MTBFs for the elemental levels are increased, the ATBO does not increase linearly as expected, since the ATBO for Assembly 38 also includes other elements of the system. The bar graph

TABLE 1 Estimated Values of Availability (AV), Reliability (RE) and Dependability (DE) for the Ka-Band SATCOM Set using all Communication Links. TASA Nr. 2

RUN ONE

Consequence state	Malfunction/ Failure Definition	AV	RE	DE	Maintainability Minutes
0	Normal Operation	0.9706	0.8205	0.7964	---
1	System Failure	(1 - 0.0100)	(1 - 0.0639)	(1 - 0.0713)	80.0
2	Malfunction/Failure 3 Links but not System Failure	0.9989	0.9917	0.9910	76.0
4	Malfunction/Failures 2 Links	0.9951	0.9722	0.9689	140.0
7	One Link inoperative	0.9982	0.9818	0.9808	40.0
8	One Link Degraded	0.9963	0.9748	0.9726	59.0

TABLE 2 Estimated Values of Availability (AV), Reliability (RE), Dependability (DE) for the Ka-Band SATCOM Set Mission using only One Link.
RUN ONE

Consequence State	Malfunction/Failure Definition	AV	RE	DE	Minutes Maintainability
TASA Nr. 6	10 Hours Mission - Only Forward Link (FWD)				
0	Normal Operation	0.855	0.9699	0.8293	-
1	Inoperative Forward Lk.	(1 - 0.110)	(1 - 0.0256)	(1 - 0.132)	93.0
2	Degraded Forward Link	0.9609	0.9956	0.9660	165.0
TASA Nr. 7	10 Hours Mission - Only Report Back Link (R/B)				
0	Normal Operation	0.9010	0.9610	0.8660	-
1	Inoperative R/B Link	(1 - .0764)	(1 - .0327)	(1 - .1047)	72.0
2	Degraded R/B Lnk	0.9729	0.9934	0.9738	59.0
TASA Nr. 8	10 Hours Mission - Only Conference Link (CONF)				
0	Normal Operation	0.8608	0.9399	0.8091	-
1	Inoperative CONF Link	(1 - .0972)	(1 - .0458)	(1 - .1360)	91.0
2	Degraded CONF Link	0.9621	0.9837	0.9521	148.0

TABLE 3. Expected Malfunctions at Selected Levels of MTBF for Elements E35 and E81

RUN TASA Nr.	ONE x1.0	TWO x1.3	THREE x1.5	FOUR x1.7	FIVE x2.0	SIX x2.5	SEVEN x3.0	EIGHT MTTR = 1 hr for E35,E81
E35	30.5	23.5	20.3	17.9	15.3	12.2	10.2	30.5
E81	10.5	8.1	7.0	6.2	5.3	4.2	3.5	10.5
38	14.	12.	11.	10.	9.3	8.3	7.6	8.3
39	16.	14.	13.	12.	11.	10.	10.	10.
200	20.	18.	17.	16.	15.	14.	14.	14.
6	171.	163.	160.	157.	154.	150.	148.	170.
7	134.	134.	134.	134.	134.	134.	135.	135.
8	190.	184.	180.	178.	175.	172.	170.	190.
2	204.	199.	196.	194.	192.	190.	189.	203.
ATBO for Assembly 38	122.4	139.	147.	154.	164.	175.	184.	122.4

Note: Malfunctions per 10,000 Hours of Operation

Table 4. Availability Values at Selected Levels of MTBF for Elements E35 and E81

RUN TASA Nr.	ONE x1.0	TWO x1.3	THREE x1.5	FOUR x1.7	FIVE x2.0	SIX x2.5	SEVEN x3.0	EIGHT MTTR = 1 hr for E35,E81
E35	0.9930	0.9946	0.9953	0.9959	0.9965	0.9972	0.9977	0.9970
E81	0.9968	0.9976	0.9979	0.9981	0.9984	0.9987	0.9989	0.9989
38	0.9857	0.9880	0.9890	0.9898	0.9907	0.9910	0.9924	0.9917
39	0.9837	0.9859	0.9869	0.9877	0.9886	0.9896	0.9903	0.9896
200	0.9799	0.9821	0.9831	0.9838	0.9847	0.9857	0.9863	0.9857
6	0.8550	0.8620	0.8652	0.8676	0.8704	0.8736	0.8757	0.8565
7	0.9010	0.9006	0.9004	0.9002	0.9000	0.8998	0.8997	0.9002
8	0.8608	0.8666	0.8693	0.8714	0.8777	0.8764	0.8782	0.8625
2	0.9706	0.9726	0.9736	0.9743	0.9750	0.9759	0.9765	0.9759

for availability values at selected levels of MTBF and MTTR for Elements E35 and E81, in Figure 11 shows a slight increase in availability for TASA Nr. 2, TASA Nr. 6 (FWD) and TASA Nr. 8 (CONF). No change in the total system availability for TASA Nr. 7 (R/B) was depicted because no transmitter (E35 and E81) was involved. Figure 12 depicts changes in ATBO, Availability and Malfunction values for Assembly 38 in relationship to changes in MTBF for Elements 35 and 81.

SYSTEM COST ESTIMATES

In most programs it is necessary to operate within certain monetary constraints, and the available funding obviously has major impact on the technical capabilities of any system to be procured. Information on costing is needed so that intelligent decisions may be made in order to obtain satisfactory equipment at an acceptable cost.

The Avionics Laboratory had access to the PRICE costing model developed by RCA, (Reference 14). The model, stored in a computer, can estimate the cost of a variety of items, including airborne electronic equipment. To obtain the cost estimate, the values for the system nonperformance parameters were inputed into the model. These included such items as weight, volume, parts count and power dissipation. The PRICE model does not accept performance parameters such as power output, frequency stability, receiver sensitivity, and reliability in a direct, discrete manner. However, the PRICE model includes a memory bank in which is stored nonperformance parametric information for (1) equipment similar to that under study, (2) cost information on this similar (that is, relatable) equipment, and (3) equations or algorithms that establish relationships between the various parameters and cost, were largely developed

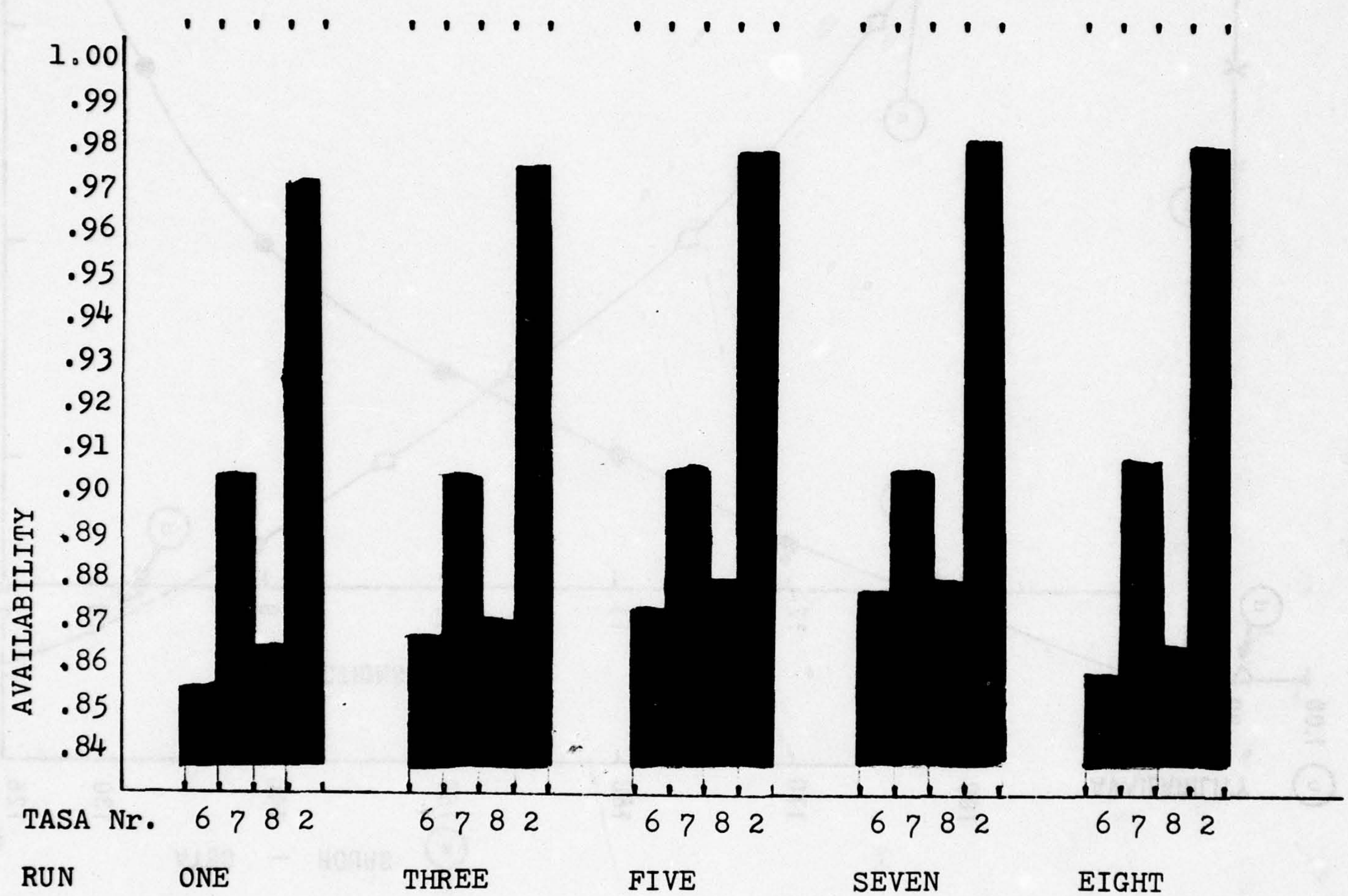

Figure 11 Bar Graph of Availability Values at selected levels of MTBF for Elements E35 and E81.

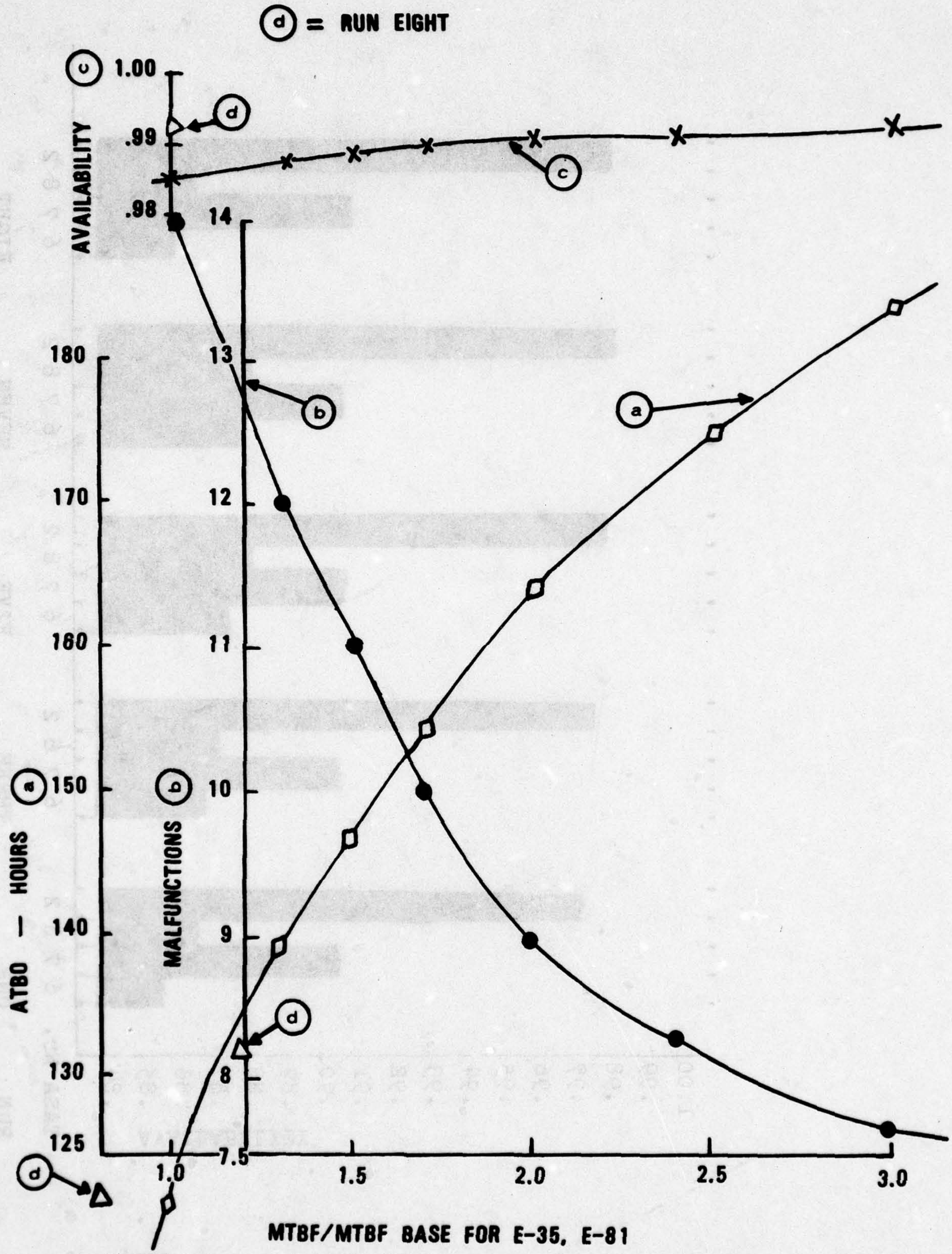

FIGURE 12 ATBO, AVAILABILITY AND MALFUNCTION VARIATIONS FOR ASSEMBLY 38

as the result of past experience. The computer compares the parameters of the new equipment with those of the equipment in its memory bank applies the proper algorithms, and thus determines an estimated cost for the equipment under study. Practical results have been obtained by other Air Force users of the PRICE model, sometimes within 10 percent of the actual cost.

Battelle, as reported in AFAL-TR-78-135, separated the Ka-Band equipment under test into functional boxes, permitting characterization of individual system performance modes [14]. Although the PRICE model analyzed equipment only as blocks of hardware, the various hardware subsystems can be gathered into these same functional groupings. Table 5 lists some of the major contributors to system unreliability in terms of percentage contribution to system cost.

Cost estimates for the Ka-Band SATCOM Set and for assemblies making up the set were prepared using the PRICE model approach described in a previous section and in Reference 14. Problem boxes were identified by the methods discussed in Chapter 3 and Appendix D as those subsystem units which were most likely to fail. Particular attention was given to these boxes to determine the cost effect of increases in their MTBFs. These results are shown in Figure 13 which gives the cost-MTBF relationships for these components. Trade off analysis using these results will be prepared by the methods discussed in Section IV and Appendix E.

TABLE 5 CONTRIBUTION TO SYSTEM COST

Identification	Percentage System Cost
Self Test Unit	7.3
Report-Back Demodulator	6.5
Message Processor	6.1
Sync/Demux Control	5.6
Code Generator	4.9
Low Noise Amplifier	4.6
Forward/Report-Back Deinterleaver/Decoder	3.7
High Voltage Power Supply	3.7
High Power Amplifier	3.7
Conferencing Demodulator/Decoder	3.1
Ka-Band Modem Control Panel	3.1
Modulator	2.9
Antenna Pointing Electronics	2.7

Source: AFAL-TR-78-135

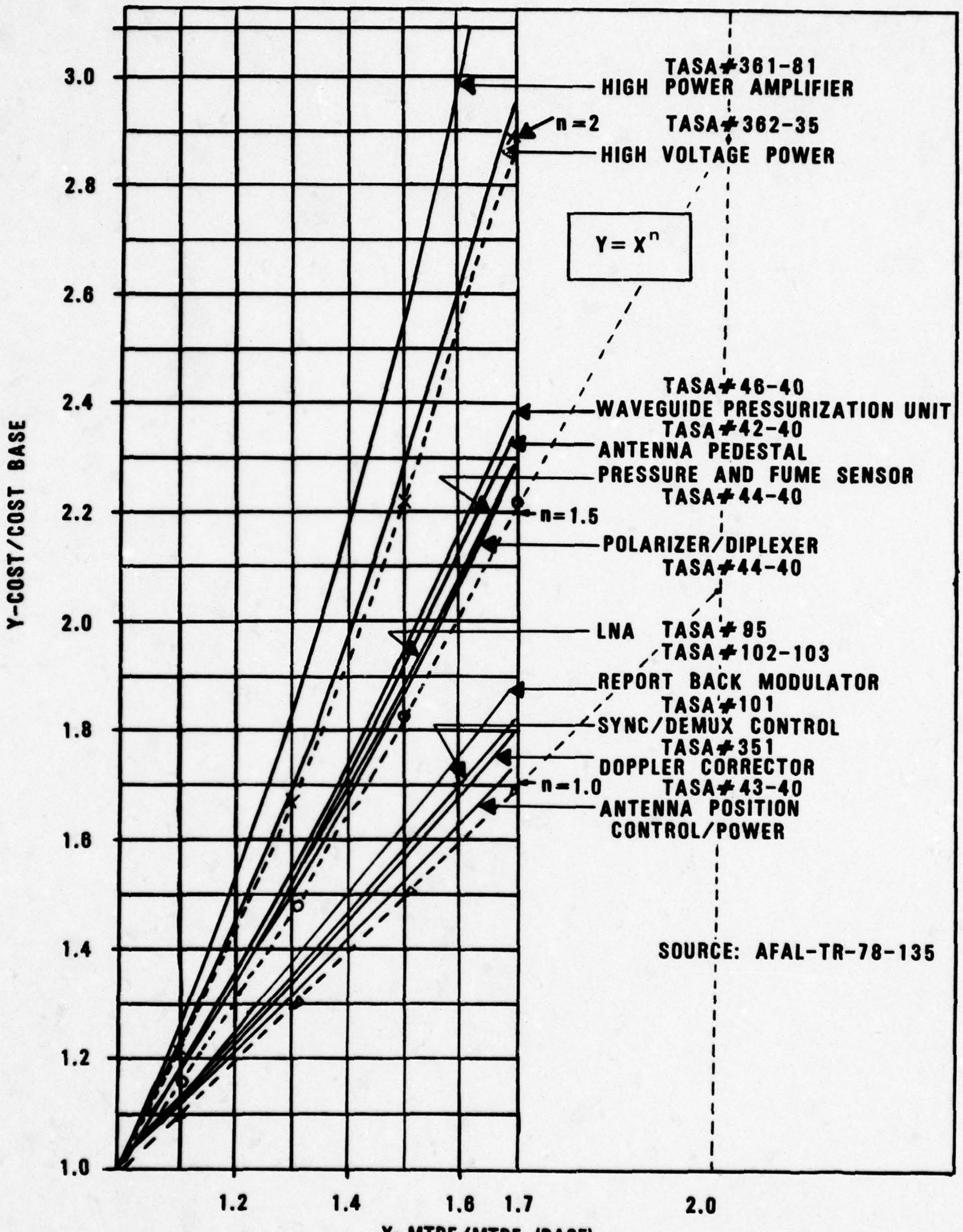

FIGURE 13 COST-MTBF RELATIONSHIPS FOR SELECTED KA-BAND EQUIPMENT

SECTION III

PERCENTAGE CONTRIBUTION OF AN ELEMENT TO THE TOTAL SYSTEM

INTRODUCTION

The DEPEND Program, as described in Section II, has a unique capability for tabulating the values of a subassembly sensitivity to an assembly - in terms of percentage contribution of each element or subassembly state - to the unavailability, unreliability and undependability of each defined assembly state. An example is given in Figures 14 and 15.

Thus, the relative importance of each element or subassembly state to the malfunctioning or failure of the assembly can be observed. This provides a rational basis for allocating resources to achieve improvement of the assembly reliability and/or maintainability and a basis for specifying "ility" requirements for the element and subassembly to assure that the assembly meets the "ility" goals.

TASA NR. 2 - TOTAL SYSTEM PERCENTAGE CONTRIBUTION

When the relative importance ranking procedure described in Appendix D of this report is applied to the functional hierarchy of the ADM Ka-Band SATCOM Set (TASA Nr. 2), the results given in Table 6 and Figures 14 and 15 are obtained. These bargraphs and tables indicate that the percentage contribution, as related to unavailability, unreliability and undependability for two functional subassemblies, accounted for more than 40% of the observed total of 14 subassemblies. Thus, the Terminal Transmission Subassembly (TASA 35-81) is the most significant contributor as related to unavailability while the MODEM common functions (TASA 108) ranked second.

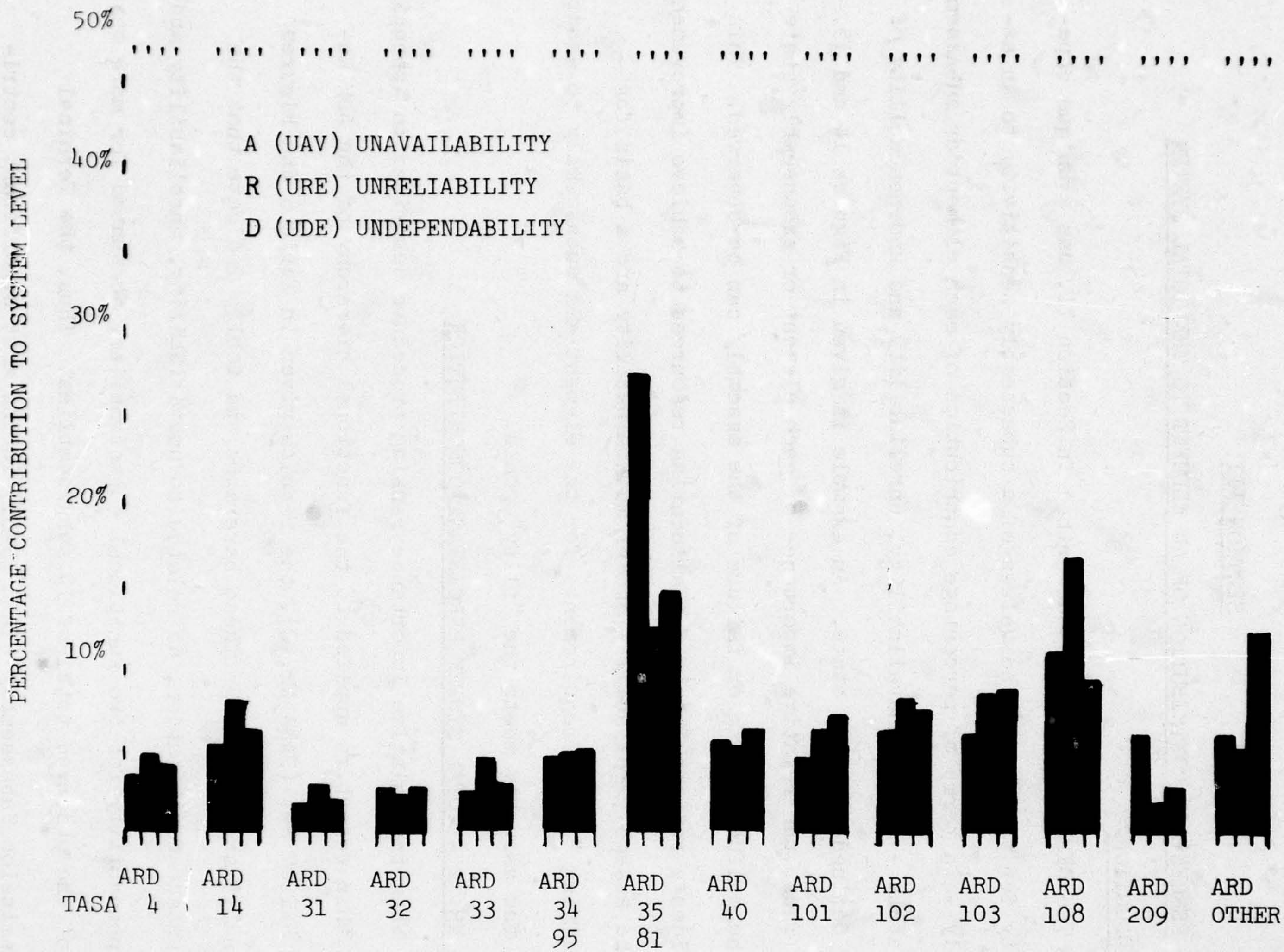

Figure 14. SATCOM SET #2 RUN ONE
ELEMENT PERCENTAGE CONTRIBUTION TO SYSTEM LEVEL

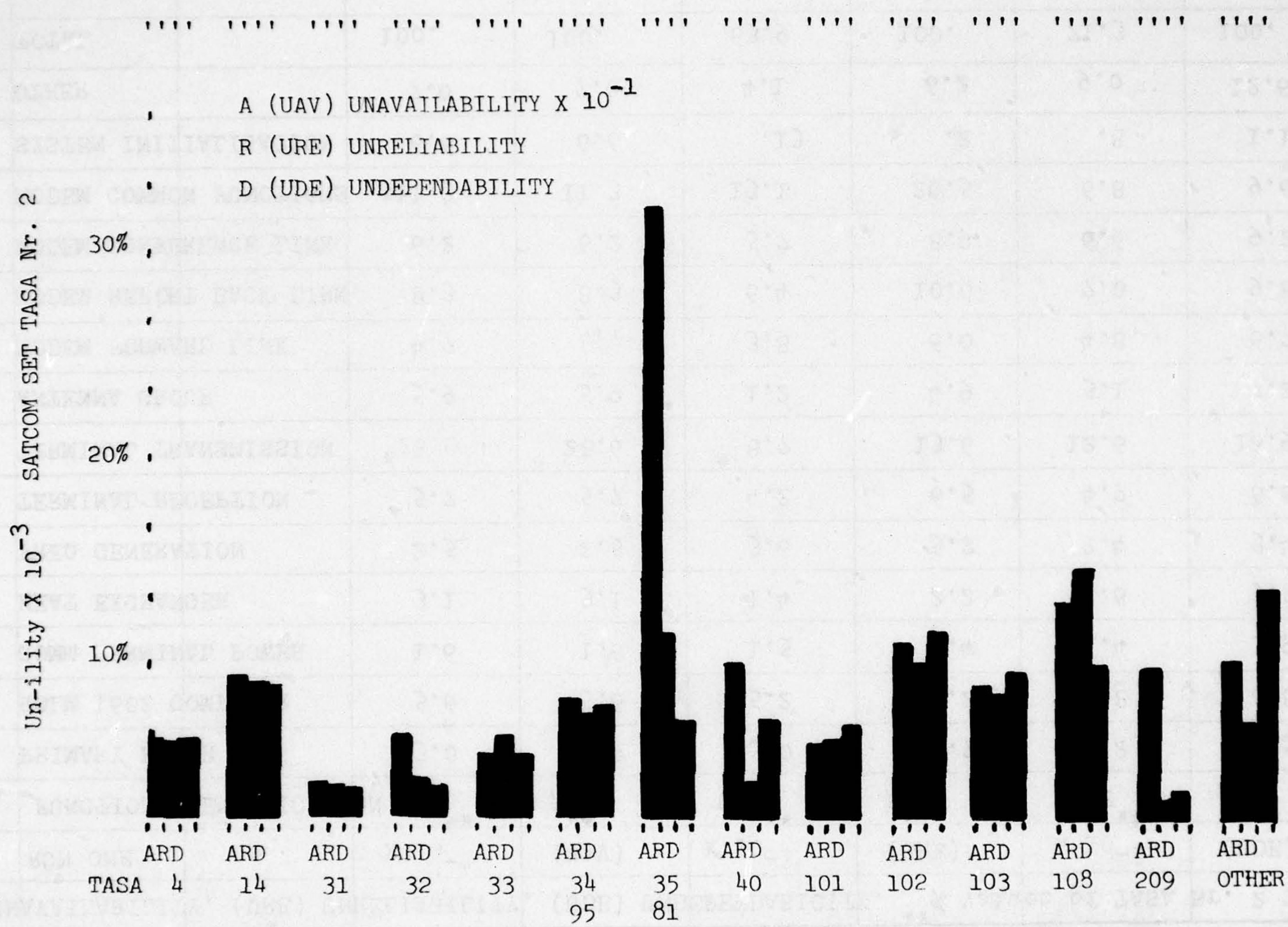

Figure 15. SATCOM SET #2 RUN ONE
"UN-ILITIES" COMPARED TO ELEMENTAL BASE

TABLE 6 FUNCTIONS CONTRIBUTING MOST SIGNIFICANTLY* TO THE Ka-Band SATCOM SET (TASA Nr.2)

(UAV) UNAVAILABILITY, (URE) UNRELIABILITY, (UDE) UNDEPENDABIOITY. ** % Values of TASA Nr. 2 Total

	RUN ONE	X 10^{-4}	(UAV)	X 10^{-3}	(URE)	X 10^{-3}	(UDE)
TASA Nr.	FUNCTION IDENTIFICATION	UAV**	%**	URE**	%**	UDE**	%**
4	PRIMARY POWER	3.0	2.9	3.0	4.7	3.2	4.5
14	ROLM 1602 COMPUTER	5.6	5.6	5.2	8.2	4.8	6.8
31	COMM TERMINAL POWER	1.6	1.6	1.5	2.4	1.4	1.9
32	HEAT EXCHANGER	3.1	3.1	1.4	2.2	2.6	3.7
33	FREQ GENERATION	2.5	2.5	3.6	5.7	2.4	3.4
34-95	TERMINAL RECEPTION	5.7	5.7	4.2	6.5	4.7	6.6
35-81	TERMINAL TRANSMISSION	*28.6	28.6	*8.7	13.6	12.6	16.9
40	ANTENNA GROUP	5.9	5.9	1.2	4.9	5.1	7.2
101	MODEM FORWARD LINK	4.7	4.7	3.8	6.0	4.8	6.7
102	MODEM REPORT BACK LINK	8.3	8.3	6.4	10.0	7.0	9.8
103	MODEM CONFERENCE LINK	6.2	6.2	5.7	8.9	6.6	9.2
108	MODEM COMMON FUNCTIONS	*11.3	11.3	13.1	20.5	6.8	9.6
209	SYSTEM INITIALIZATION	6.6	6.6	.13	.2	.8	1.1
	OTHER	7.0	7.0	4.1	6.2	9.0	12.6
	TOTAL	100.	100.	63.9	100.	71.3	100.

TASA NR.'s 35 and 81 PERCENTAGE CONTRIBUTIONS AT SELECTED RUNS

The MTBF and MTTR for Elements 35 and 81 were varied in the manner discussed in Section II. Table 11 is a compilation of the results given in Tables 7 through 10. RUNS FIVE, SEVEN, and EIGHT data show that the total percentage contribution in terms of unavailability for Elements 35 and 81 to TASA Nr. 2 is reduced when compared to RUN ONE data. This would indicate an improvement in either MTBF or MTTR. However, cost will be addressed in the next Section in terms of trade-offs to determine the most economical alternatives based on selected runs in relationship to a specified availability as a goal.

SUMMARY AND CONCLUSIONS

A primary goal of the procedure for relative importance ranking of each element to the malfunction or failure of the assembly was to identify the functional assemblies of the Ka-Band SATCOM Set that have the greatest influence on the system "ilities." The results of these studies are described in Appendix D. The studies used the sensitivity tabulations printed by the DEPEND Program. These tabulations are given in Appendix D.

Thus a capability was demonstrated that can be used to determine which element could have the greatest influence on system "ilities" in terms of various alternatives for a trade-off between cost and improved performance. Improved performance could include reliability improvement as a result of redundancy, derating, or redesign and maintainability improvement which could otherwise require increased training, spares and accessibility.

TABLE 7 PERCENTAGE CONTRIBUTION SUBASSEMBLY TO SYSTEM — RUN ONE

X UNAVAILABILITY ___ UNRELIABILITY ___ UNDEPENDABILITY

% Assy State-Sys A	Assy ID B	% Assy State C	Sys ID D	Number of Subassy E	Subassy ID E'	%Subassy State A'	%Subassy to Sys
24.6	208.6	12.7	2.6	1	204.7	10.9	21.1
21.1	204.7	33.5		1	200.7	33.4	21.1
21.1	200.7	36.7		1	39.6	28.1	16.1
16.1	39.6	35.2		1	38.6	35.1	16.1
16.1	38.6	40.5		1	E 35.2	35.0	13.9
16.1	38.6	40.5		1	E 35.3	5.4	2.1
16.8	208.4	13.8	2.4	1	204.5	12.9	15.7
15.7	204.5	23.5		1	200.5	23.4	15.6
15.6	200.5	25.8		1	39.5	20.8	12.6
12.6	39.5	26.0		1	38.5	26.0	12.6
12.6	38.5	30.1		1	E 35.1	8.2	3.4
12.6	38.5	30.1		1	E 81.1	21.9	9.2
24.8	208.1	24.3	2.1	1	204.1	22.8	23.3
23.3	204.1	34.7		1	200.1	25.7	17.2
17.2	200.1	28.3		1	39.1	23.6	14.4
14.4	39.1	29.6		1	40.1	12.8	6.2
14.4	39.1	29.6		1	38.1	16.6	8.1
8.1	38.1	19.3		1	E 31.1	4.2	1.8
8.1	38.1	19.3		1	E 32.1	7.8	3.3
8.1	38.1	19.3		1	E 33.1	7.2	3.0

TABLE 8 PERCENTAGE CONTRIBUTION SUBASSEMBLY TO SYSTEM RUN FIVE

X UNAVAILABILITY ___ UNRELIABILITY ___ UNDEPENDABILITY

% Assy State-Sys A	Assy ID B	% Assy State C	Sys ID D	Number of Subassy E	Subassy ID E'	%Subassy State A'	%Subassy to Sys
18.7	208.6	9.5	2.6	1	204.7	7.7	15.2
15.2	204.7	26.6		1	200.7	26.5	15.1
15.1	200.7	30.0		1	39.6	18.6	9.4
9.4	39.6	25.3		1	38.6	25.3	9.4
9.4	38.6	31.3		1	E 35.2	27.1	8.1
9.4	38.6	31.3		1	E 35.3	4.2	1.3
12.0	208.4	10.7	2.4	1	204.5	9.9	11.1
11.1	204.5	18.0		1	200.5	17.9	11.0
11.0	200.5	20.3		1	39.5	13.8	7.5
7.5	39.5	18.1		1	38.5	18.8	7.5
7.5	38.5	23.2		1	E 35.1	6.3	2.0
7.5	38.5	23.2		1	E 81.1	16.9	5.5
29.8	208.1	26.6	2.1	1	204.1	25.1	27.9
27.9	204.1	44.7		1	200.1	33.3	20.8
20.8	200.1	37.5		1	39.1	31.4	17.4
17.4	39.1	42.6		1	40.1	18.4	7.5
17.4	39.1	42.6		1	38.1	24.1	9.8
9.8	38.1	29.8		1	E 31.1	6.5	2.1
9.8	38.1	29.8		1	E 32.1	12.0	3.9
9.8	38.1	29.8		1	E 33.1	11.2	3.7

TABLE 9 PERCENTAGE CONTRIBUTION SUBASSEMBLY TO SYSTEM RUN SEVEN

X UNAVAILABILITY ___ UNRELIABILITY ___ UNDEPENDABILITY

% Assy State-Sys A	Assy ID B	% Assy State C	Sys ID D	Number of Subassy E	Subassy ID E'	%Subassy State A'	%Subassy to Sys
16.0	208.6	8.3	2.6	1	204.7	6.5	12.5
12.5	204.7	23.3		1	200.7	23.3	12.5
12.5	200.7	26.6		1	39.6	13.9	6.5
6.5	39.6	19.8		1	38.6	19.8	6.5
6.5	38.6	25.5		1	E 35.2	22.1	5.7
6.5	38.6	25.5		1	E 35.3	3.4	0.8
9.9	208.4	9.5	2.4	1	204.5	8.8	9.2
9.2	204.5	15.4		1	200.5	15.3	9.1
9.1	200.5	17.6		1	39.5	10.3	5.3
5.3	39.5	14.7		1	38.5	14.7	5.3
5.3	38.5	18.9		1	E 35.1	5.1	1.4
5.3	38.5	18.9		1	E 81.1	13.8	5.6
31.9	208.1	27.5	2.1	1	204.1	25.9	30.0
30.0	204.1	49.4		1	200.1	36.9	22.4
22.4	200.1	42.1		1	39.1	35.2	18.8
18.8	39.1	49.9		1	40.1	21.5	8.1
18.8	39.1	49.9		1	38.1	28.3	10.7
10.7	38.1	36.4		1	E 31.1	7.9	2.3
10.7	38.1	36.4		1	E 32.1	14.7	4.3
10.7	38.1	36.4		1	E 33.1	13.7	4.0

TABLE 10 PERCENTAGE CONTRIBUTION SUBASSEMBLY TO SYSTEM RUN EIGHT

X UNAVAILABILITY ___ UNRELIABILITY ___ UNDEPENDABILITY

% Assy State-Sys A	Assy ID B	% Assy State C	Sys ID D	Number of Subassy E	Subassy ID E'	%Subassy State A'	%Subassy to Sys
15.3	208.6	10.5	2.6	1	204.7	8.8	12.8
12.8	204.7	21.8		1	200.7	21.7	12.8
12.8	200.7	24.8		1	39.6	12.7	6.5
6.5	39.6	17.7		1	38.6	17.7	6.5
6.5	38.6	22.4		1	E 35.2	17.7	5.1
6.5	38.6	22.4		1	E 35.3	4.7	1.4
12.7	208.4	13.0	2.4	1	204.5	12.1	11.8
11.8	204.5	19.5		1	200.5	19.5	11.8
11.8	200.5	22.1		1	39.5	15.2	8.1
8.1	39.5	21.1		1	38.5	21.1	8.1
8.1	38.5	26.7		1	E 35.1	14.1	4.3
8.1	38.5	26.7		1	E 81.1	12.6	3.8
31.0	208.1	25.4	2.1	1	204.1	23.9	29.2
29.2	204.1	47.3		1	200.1	35.3	21.8
21.8	200.1	40.1		1	39.1	33.5	18.2
18.2	39.1	46.6		1	40.1	20.1	7.8
18.2	39.1	46.6		1	38.1	26.3	10.3
10.3	38.1	33.3		1	E 31.1	7.3	2.3
10.3	38.1	33.3		1	E 32.1	13.5	4.2
10.3	38.1	33.3		1	E 33.1	12.5	3.8

TABLE 11 PERCENTAGE CONTRIBUTION TO ASSEMBLY TASA Nr. 2 UNAVAILABILITY BY ELEMENTS TASA Nr. 35 AND 81.

TASA Nr.	35.1	35.2	35.3	81.1	TOTAL
RUN ONE	3.4	13.9	2.1	9.2	28.6
RUN FIVE	2.0	8.1	1.3	5.5	16.9
RUN SEVEN	1.4	5.7	0.8	5.6	13.5
RUN EIGHT	4.3	5.1	1.4	3.8	14.6
TASA Nr.	2.4	2.8	2.6	2.4	35 & 81

SECTION IV

TRADE-OFF ANALYSIS IN THE SUBSYSTEM DESIGN PHASE

INTRODUCTION

A basic selection criterion for trade-offs during the design phase of an avionic system is the dollar cost. The costs associated with each equipment design alternative are computed, and the least costly alternative that provides the desired system effectiveness is selected. The costs associated with alternative designs are composed of such cost categories as design, development, acquisition and operation. The general costs contributing to the categories discussed in this report are shown in Figure 16. More specifically, the equipment design and development costs and maintenance or repair costs presented in this study are hypothetical.

Making an equipment more reliable will usually increase its initial cost. This increase can, however, be more than offset by economics in maintenance and repair costs. When an equipment fails, there is a loss of service which results in system unavailability, and directly affects the mission. Also, it may be necessary to provide one or more costly avionic systems as standby. Thus, the lower the reliability or maintainability, the more unavailable the system will become and the higher the number of extra systems which must be provided. Besides the increased equipment unavailability, there is the increased cost of repair and maintenance.

As discussed by Blanchard and Lowry in their text entitled

DEPENDABILITY

AVAILABILITY

RELIABILITY	MAINTAINABILITY
Cost of Failure Reporting	Maintenance and Repair Cost
Related Cost of Design and Development	Spares Cost
Manufacturing Costs	Related Cost of Design and Development
Quality Assurance Testing	Standby Equipment
	Total Repair Manhours
	Technician Training
	Cost of Testing

Figure 16. General Cost Categories relating to the Equipment Reliability and Maintainability Design

"Maintainability", trade-off techniques must not depend on an intuitive process when considering increasingly complex systems and resulting high cost in making a realistic decision [4]. One trade-off application, for example, is that of cost of design for system reliability improvement versus cost of design for system maintainability improvement, in order to achieve a specified system availability at a minimum total life cost.

Trade-off analysis at the system level should be initiated in the conceptual phase of a program to assess minimum investment before design finalization and resulting costly retrofit later. Trade-offs at subsystem levels are normally conducted during the definition phase, while trade-offs at the detail level will, in all probability, be accomplished in the advanced development and acquisition phase of the system.

MINIMIZING TOTAL SYSTEM COST

The initial step in any optimization procedure should be an examination of the various alternatives for possible trade-off between the Research and Development (R&D) investment and the annual operation and maintenance cost. As discussed by Seiler in his text entitled "System Cost Effectiveness", the total system cost may be reduced without changing system effectiveness, by adjusting the balance between the R&D investment and operation costs wherein the total cost, $TC = R+I+O$, is a minimum [27]. Period costing is the most commonly used method of comparing the cost of alternative systems over a set interval of time. It represents the summary of all system costs for a

fixed period of time, including annual maintenance and operating cost, plus the annual equivalent cost of R&D investment at an interest rate of 9% for a total system life use of ten years.

Cost estimates for the Ka-Band SATCOM Set under this study and for the assemblies making up this set were generated by Battelle, using the PRICE MODEL approach described in Section II, in Appendix B of this report and in Technical Report AFAL-TR-78-135 [14]. The subsystems units most likely to fail were identified. Particular attention was given to these units to determine the effect of cost increase based on changes in their MTBF's. Finally, one subassembly, the High Voltage Power Supply, was selected for trade-off techniques demonstration. Figure 13 in Section II illustrates the relationship of increasing cost to MTBF improvement, suggesting that the cost to MTBF ratio for the item under consideration should be viewed as a square function. However, an improvement in assembly maintainability, which is a reduction in restoration time by a factor of 2, would result in an increase in acquisition cost of 7%, as discussed in AFSC Design Handbook 1-9 [32]. This would suggest that the same increase in the equipment availability would result in a substantial cost increase when reliability improvement is addressed, but a small increase when maintainability improvement is considered. This would demonstrate that for similar increases in system availability, the maintainability equipment cost would be less.

A minimum cost decision model was used in computing the results reported in Tables 12, 13, 14, 15, and 16. The model is described in

TABLE 12 RELIABILITY IMPROVEMENT FOR ELEMENT 35
SEE PROGRAM CODING, APPENDIX E

DATA			REGISTER	OUTPUT
0.		00		
10.	N	01	10.000	
9.	I	02	9.000	
1.126966588	Mr	03	6.418	MINIMUM
1.270053691	Cr	04		COST
328.	MF	05	328.000	63.263
406.	CD	06	406.000	181.098
11.	CF	07	11.000	1.431
0.09		08	2.000	1.127 XMP
1.09		09		
6.417657701	PWF	10	RUN ONE	
16.46341463	FB	11	1.000	1.127
2.367363675		12	1.000	1.270
80.34735141	CR	13		
160.6947028	CM	14		
241.0420542	TC	15		
2.	n	16	16.463	14.609
14.60860935	Fyr	17	63.263	80.347
63.2629565	A	18	181.098	160.695
181.097561	B	19	244.361	241.042
1.126966588	XMP	20		
0.		21		

TABLE 13 RELIABILITY IMPROVEMENT FOR ELEMENT 35
n = 2.0 (Alternative A)

N	10.000							
I	9.000		MINIMUM COST					
PWF	6.418							
MF	328.000		63.263					
CD	406.000		181.098					
CF	11.000		1.431					
n	2.000	XMP	1.127		RUN TWO	RUN THREE	RUN FOUR	RUN FIVE
	RUN ONE							
Mr	1.000	1.100	1.127	1.200	1.300	1.500	1.700	2.000
Cr	1.000	1.210	1.270	1.440	1.690	2.250	2.890	4.000
Fyr	16.463	14.967	14.609	13.720	12.664	10.976	9.684	8.232
CR	63.263	76.548	80.347	91.099	106.914	142.342	182.830	253.052
CM	181.098	164.634	160.695	150.915	139.306	120.732	106.528	90.549
TC	244.361	241.182	241.042	242.013	246.220	263.073	289.358	343.601
AVAILABILITY	0.9930				0.9946	0.9953	0.9959	0.9965

TABLE 14 RELIABILITY IMPROVEMENT FOR ELEMENT 35

n = 1.5

10.000							
9.000			MINIMUM				
6.418			COST				
328.000			63.263				
406.000			181.098				
11.000			1.908				
1.500		XMP	1.295				
RUN ONE				TWO	THREE	FOUR	FIVE
1.000	1.100	1.200	1.295	1.300	1.500	1.700	2.000
1.000	1.154	1.315	1.474	1.482	1.837	2.217	2.828
16.463	14.967	13.720	12.713	12.664	10.976	9.684	8.232
63.263	72.986	83.161	93.229	93.770	116.221	140.224	178.935
181.098	164.634	150.915	139.844	139.306	120.732	106.528	90.549
244.361	237.620	234.076	233.073	233.076	236.953	246.752	269.483

TABLE 15 RELIABILITITY IMPROVEMENT FOR ELEMENT 35

n = 1.0

10.000							
9.000					MINIMUM COST		
6.418							
328.000					63.263		
406.000					181.098		
11.000					2.863		
1.000				XMP	1.692		
RUN ONE			TWO	THREE		FOUR	FIVE
1.000	1.100	1.200	1.300	1.500	1.692	1.700	2.000
1.000	1.100	1.200	1.300	1.500	1.692	1.700	2.000
16.463	14.967	13.720	12.664	10.976	9.731	9.684	8.232
63.263	69.589	75.916	82.242	94.894	107.036	107.547	126.526
181.098	164.634	150.915	139.306	120.732	107.036	106.528	90.549
244.361	234.223	226.830	221.548	215.626	214.073	214.075	217.075

TABLE 16 MAINTAINABILITY IMPROVEMENT FOR ELEMENT 35
(Alternative B)

DATA	REGISTER	
0.	00	
10.	01	N
9.	02	I
1.101834706	03	My
1.21403972	04	CP
328.	05	MF
434.42	06	CDM
11.	07	CF
0.09	08	
1.09	09	
6.417657701	10	PWF
16.46341463	11	FB
2.367363675	12	
82.18000393	13	CR
164.3600079	14	CM
246.5400118	15	TC
2.	16	n
14.9418189	17	
67.69136346	18	A
181.097561	19	B
1.101834706	20	XMP
0.	21	

OUTPUT			
CD	406.	x	
	1.07	=	
CDM	434.420		
MF	328.000	67.691	
DCM	434.420	181.098	
CF	11.000	1.338	
n	2.000	1.102	
My	1.000	1.102	1.200
Cy	1.000	1.214	1.440
Fyr	16.463	14.942	13.720
CR	67.691	82.180	97.476
CM	181.098	164.360	150.915
TC	248.789	246.540	248.390
AVAILABILITY	0.9970	0.9970	

Appendix E, with calculation procedures and base line assumptions as presented. The MTBF was varied from the base line RUN ONE with MTBF to MTBF (BASE) ratio as 1.0 to RUN FIVE when the ratio is 2.0. The corresponding availabilities value were computed using the TASA/DEPEND program as described in Section II and Appendices A, B and C. Also, the exponent n of the MTBF ratio (X) was varied, as shown in Tables 13, 14, and 15.

In RUN EIGHT the MTBF ratio was set to 1 and the exponent n of the MTBF ratio was set to 2. The MTTR values for Elements 38 and 81 were set to one hour. The results are in Table 16 in terms of availability as given in Appendix C. The results of Tables 13 and 16 are presented in Figures 17 and 18.

RELIABILITY IMPROVEMENT COST ESTIMATES

Table 12 lists the data stored in the data register of the Programmable Calculator TI-58 with the output as printed on the PC-100A printer [31]. The program coding and user instruction are given in Appendix E. The computation procedures are also given with definition for the various parameters such as N, I, M_r, etc. A base line, RUN ONE, was established with a MTBF ratio of M_r=1, and exponent n of 2. Repair cost for one failure of 11K dollars, equipment acquisition cost of \$406K, MTBF of 328 hours, N of 10 year operation period, and I rate per year of 9% were assumed. The MTBF ratio (M_r) for minimum cost was calculated as 1.127. This was based on the assumptions discussed in Appendix E, resulting in a total annual equivalent cost (TC) of

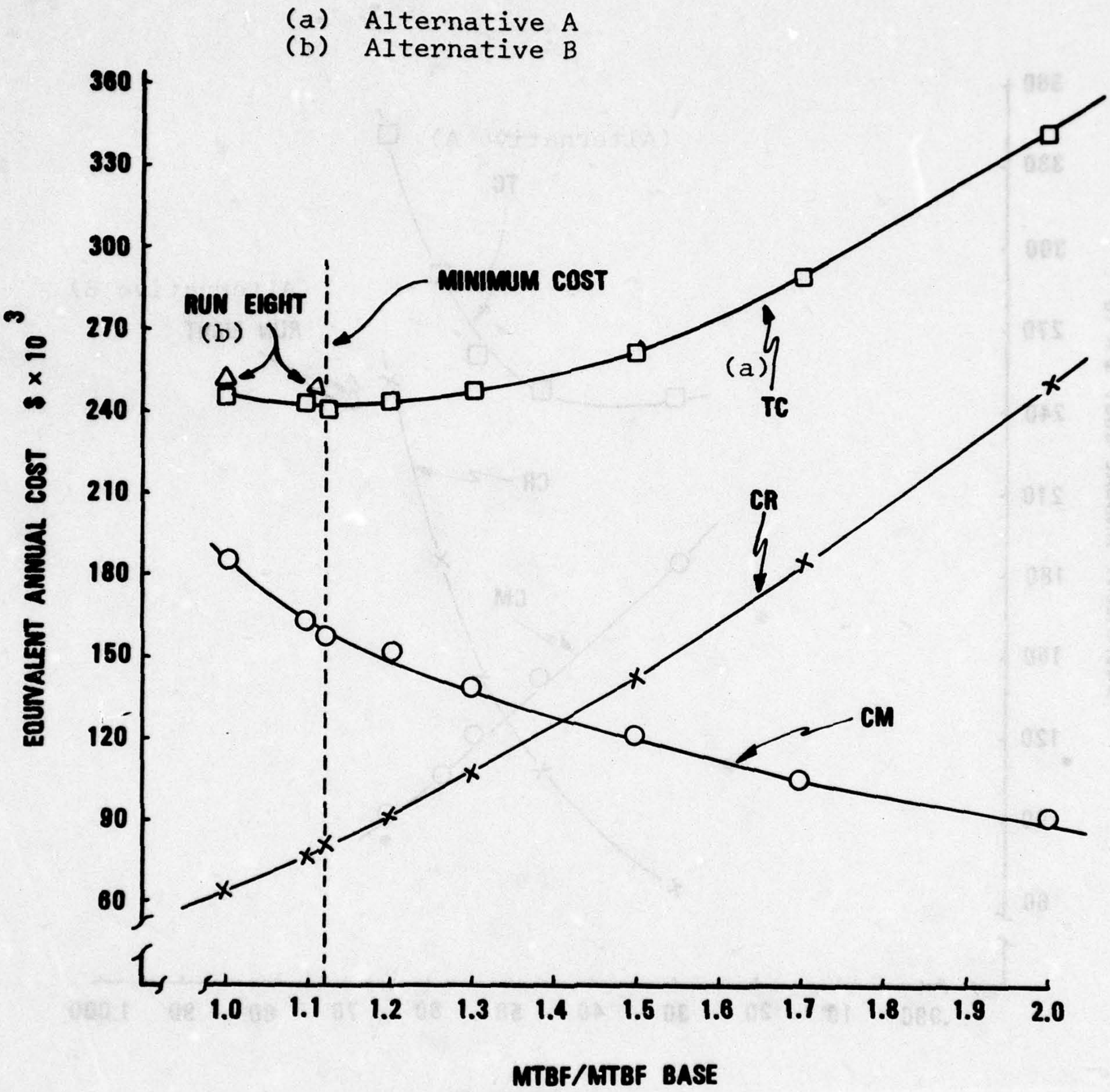

FIGURE 17. VARIATION OF COST TO MTBF, n = 2.0 FOR ELEMENT 35

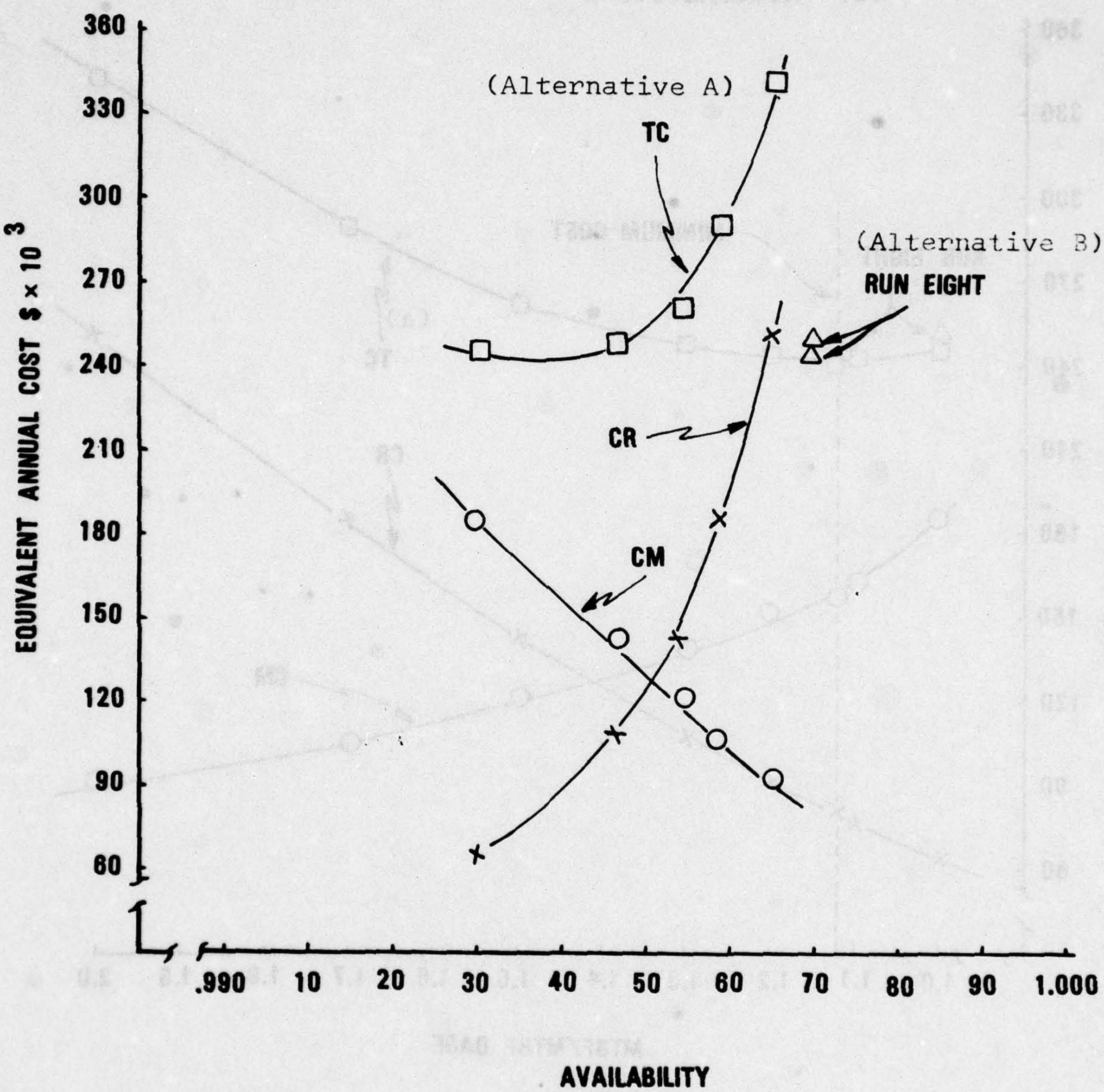

FIGURE 18. VARIATION OF COST TO AVALABILITY, n = 2.0 FOR ELEMENT 35

$241,042. Table 13 shows again the minimum cost at $241,042 and increasing cost at RUN ONE, (M_r=1), and RUNS TWO, THREE, FOUR, and FIVE. Also, as the MTBF is increased from 328 hours to 656 hours, availability increases to 0.9965 with approximately a 50% increase in total cost from minimum total cost.

In Table 14, n was set at 1.5 and in Table 15, n equals 1.0 as a straight line cost model. At n = 1.5, the minimum total cost is $233,073 with a MTBF ratio of 1.295 or 1.3 which is nearly the same as RUN THREE with an availability of 0.9953. At n = 1.0, the minimum total cost is $214,073 with a MTBF ratio of 1.692 or 1.7, which is nearly the same as RUN FOUR with an availability of 0.9959. However, based on the findings of Battelle using the RCA-PRICE cost model, as reported in reference 14, an exponent n of 2 will provide a reduction in cost estimate for the Element 35 under study. Another alternative under consideration was a reduction in restoration time (MTTR) as an improvement in maintainability, RUN EIGHT, as shown in Table 16.

MAINTAINABILITY IMPROVEMENT COST ESTIMATE

In RUN EIGHT, the MTBF was set to the base line of 328 hours and the MTTR changed to one hour. This resulted in an availability calculation of 0.9970 using the TASA/DEPEND MODEL. Since the MTTR was reduced by half, the acquisition cost of $406,000 for the item under study was increased to $434,420. This is based on the downtime cost relationship as discussed in AFSC Design Handbook 1-9

for maintainability [32]. Since data consisting of observed equipment down time and Research and Development initial investment cost factors affecting maintainability are not readily available, a very simple logarithmic formula, given below, can be used to represent the initial elements of the equipment maintainability design and development cost. Maintainability acquisition cost (COM) = 0.1 CD Ln Im, CD is the state-of-the-art acquisition cost. Im is the maintainability improvement ratio of the state-of-the-art downtime per failure to planned time. Thus, the equation shows that halving the active repair time, Im = 2, adds 7% to the acquisition cost.

SELECT OPTIMUM COST TO PERFORMANCE DESIGN WITH CONCLUSIONS

The cost to performance trade-offs for the equipments under study were addressed in terms of variation in cost to MTBF and cost to MTTR. See Figure 17. An Alternative A was based on minimum cost as the MTBF was varied with MTTR fixed, while Alternative B was based on changes in MTTR with a fixed MTBF for Elements 35 and 81. Both of the alternatives are presented in Figure 18 in terms of availability and its values of MTBF or MTTR. The ratio presented in Figures 17 and 18 demonstrates that the total cost of an equipment can be minimized. However, the minimum cost must be weighed against mission requirements. Therefore, Alternative B would be the better choice because the availability was increased appreciably at a modest increase in total costs.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

A practical approach (TASA/DEPEND Program) for analyzing system "ilities" has been demonstrated. This approach provides an analysis tool for studying the impact of changes in mission use profile on reliability, availability and dependability so that mission plans can be enhanced with respect to achieving design objectives as related to cost. An important feature of this analysis approach is that the impact of malfunctions and failures are separately assessed. This makes it possible to directly relate the contributions to hardware module reliability and maintainability to functional block performance. Such studies provide a means for concentrating reliability and maintainability resources in areas that will provide the maximum system improvement. Also, a rational basis for trade-offs between reliability and maintainability requirements is obtained in relationship to cost. Thus, the DEPEND Program can be a valuable tool for management of reliability/maintainability programs, development of requirements for procurement specifications, evaluations of the "ility" impact of engineering changes and the assessment of testing programs.

APPENDIX A

TASA/DEPEND PROGRAM

INTRODUCTION AND SUMMARY

This appendix discusses the use of the DEPEND computer program to obtain values for dependability, availability, reliability and related performance parameters for all the assemblies of a system's functional hierarchy. The model used with this program provides for the use of alternative malfunction and failure definitions and calculates the corresponding probabilities of assembly malfunction or failure; that is, the undependabilities, unavailabilities and unreliabilities. The DEPEND program keeps track of all the organizational details of the model and performs the arithmetic as well. The mathematical basis of this technique are described in Appendices B and C of this report.

The mathematical models, details of the analysis methods and the results obtained in an analysis of an airborne EHF communications terminal were presented in final project report (Reference 14). Part III of this report is a User's Manual, containing instructions for use of the TASA/DEPEND methodology. The complete analysis procedure consists of the three processes, (1) Tabular System Analysis (TASA), (2) acquisition of the required functional element data (MTBF or MTTR) and (3) computation using the DEPEND computer program.

TABULAR SYSTEM ANALYSIS (TASA)

The basic TASA concept as developed by Mr. Jim Drennan of Battelle, is described as a nested organization of interdependent and interacting devices operating to accomplish a specified function [8].. To assess over all system dependability, availability, or reliability, it is necessary to consider these qualities in the individual components and subsystems which are the

constituent elements. Such an assessment requires consideration of the consequences of malfunctions or failures occurring in the various subsystems, both singly and in combination, in terms of functional states of components and other assemblies that can be defined in an overall description of the system.

The first step in an application of TASA is to develop a chart or charts showing the functional relationship of the elements, assemblies and subsystems that make up the system. The partitioning of the system into functional assemblies is not critical with respect to the DEPEND program. However, it is recommended that the partitioning be done in a way that simplifies the determination of the consequences of malfunctions or failures; that it simplifies the functional complexity.

An example of a functional hierarchy that describes the upper levels of the airborne Ka-Band SATCOM Terminal is given in Section II, Figure 6. The numbers in the lower left hand corners of functional blocks are assigned for use as identifiers throughout the analysis. The Ka-Band Terminal has three primary functional links, the forward link, the report-back link and the conference link as discussed in Section II. Part of the system elements are functionally common to two or more links. Functionally common means that a malfunction or failure will cause more than one link to be degraded or inoperative. It is also necessary to consider the system initialization (start-up) function and the primary power source.

It is important to recognize that function is distributed across time as well as across hardware components. This is illustrated in Figure 6 of Section II by noting that the three links of the Ka-Band Terminal operate

for different lengths of time during a mission. To simplify the logic as well as facilitate computations, functional blocks have been added to express the transition from one functional cycle of use of a specific assembly to the transmission or reception of one message and ultimately the total numbers of messages transmitted and received during the mission.

During the development of the functional hierarchy for the system, mutually exclusive functional states are defined for each assembly and subassembly in the system hierarchy. Thus, the functional state of the system is represented as depending upon the functional states of the next lower level assemblies and so on down to the lowest level subassemblies (elements) for which meaningful functional states can be defined. The resulting arrangement of assemblies and their functional states may be thought of as a state tree. The state tree (See Appendix C) is similar to the fault tree of Fault-Tree Analysis and, indeed, that is its origin. However, the state tree is not limited to faults and can include almost anything pertinent to the system's function [5]. Furthermore, because TASA considers all possible combinations of states, the TASA state tree corresponds to all of the possible Fault Trees for the system together with the trees associated with other states that are not actually faults. The approach is demonstrated using TASA Nr. 104 in Appendix C, Figure C-1.

The third part of the TASA is the engineering determination of the functional state of each system assembly based on various combinations of the functional states of the constituent assemblies. Tabular work

sheets are provided for TASA use that list in a systematic manner selected combinations of input assembly functional states. With these tables, up to 697 separate engineering decisions can be made and documented in the analysis of each assembly [14] (Table C-2).

The basic concept underlying this part of TASA, as discussed in Appendic C, is to assume a particular combination of the functional states for all of the subassemblies that make up a given assembly and then make an engineering estimate of functional consequences in terms of the assembly functional state that would result. This process is repeated for all combinations of subassembly functional states under the practical constraints that no more than 3 subassembly functional states will be varied simultaneously.

DEPEND PROGRAM FUNCTIONAL ELEMENT DATA ACQUISITION

MTBF and MTTR data are required for each malfunction and failure state defined for each functional element of the system. In the early stages of system development, when the emphasis is placed on "ility" prediction, the procedures of MIL-HDBK-217B and AFSC DH 1-9 can be used to predict the MTBF and MTTR for each element malfunction and failure state [23] [22]. The resulting DEPEND outputs are the "ility" predictions for the system. Where actual experience data are available for the functional elements, these data can be used. In this case the DEPEND outputs are an "ility" assessment of the system. Bayesian combinations of predicted, experience and test data can also be used to generate a practical set of element MTBF and MTTR values. One procedure for making such combinations is described in Part 1 of technical

report AFAL-TR-78-135 [14]. In any case, the credibility and interpretation of the analysis results will depend on the validity and choice of the element data used. Thus, it is necessary to document and substantiate the source of element MTBF and MTTR values used as input for the DEPEND program.

USING THE DEPEND PROGRAM

The DEPEND program runs in batch mode from a punched card deck that consists of a control record, relocatable binary program, and four data records, as discussed in the User's Manual by Drennan [14]. Operation of the DEPEND program requires the user to supply four types of data: (1) output control data; (2) assembly identifications and functional state definitions; (3) element MTBF and MTTR values; and (4) functional operation data, structure data and fault consequence data.

Job Control and Data Records. The operation of the DEPEND computer code to perform the TASA calculation requires a job control record which utilizes a relocatable binary program deck.

Output Control and Title (Table A-1). The first data record consists of an output control card, followed by up to five title cards. The first card of this record (output control card) contains four logical values and the ATTR Weighting Factor, all separated by commas. A .TRUE. value of the first logical variable will cause a listing of the state identifications to be printed. If the second logical variable is .TRUE., a listing of the element MTBF and MTTR values and a listing of the corresponding reliability/unreliability and availability/unavailability

TABLE A-1 DATA RECORD ONE AND TWO

MASTER AUDIT, IDENT CARD TOTAL UPDATE 1.3-476. 05/22/79 22.58.39. PAGE

LIST OF CONTROL, ACTIVE, AND/OR INACTIVE CARDS IN DATA

DATA	*DECK DATA	DATA RECORD ONE		DATA	1	A
DATA	.TRUE...TRUE...TRUE...TRUE..,0.6			2	1	A
DATA		RUN FIVE 30108 2.0		2	2	A
DATA		KA-BAND SATCOM SET		2	3	A
DATA		PROGRAM DEPEND		2	4	A
DATA		MODIFIED		2	5	A
DATA		TRUNCATED MODEL		2	6	A
DATA	AAAAAAAAAA	DATA RECORD TWO		DATA	8	A
DATA	2.0	KA-BAND SATCOM SET (SUMMARY)		DATA	9	A
DATA	2.1	ALL KA-BAND LINKS INOPERATIVE		DATA	10	A
DATA	2.2	COMBINATION OF 1 (2) INOPERATIVE AND 2 (1) DEGRADED KA-BAND LINKS		DATA	11	A
DATA	2.3	ALL KA-BAND LINKS DEGRADED		DATA	12	A
DATA	2.4	TWO KA-BAND LINKS INOPERATIVE		DATA	13	A
DATA	2.5	ONE INOPERATIVE AND ONE DEGRADED KA-BAND LINK		DATA	14	A
DATA	2.6	TWO KA-BAND LINKS DEGRADED		DATA	15	A
DATA	2.7	ONE KA-BAND LINK INOPERATIVE		DATA	16	A
DATA	2.8	ONE KA-BAND LINK DEGRADED		DATA	17	A
DATA	101.0	KA-BAND MODEM GROUP (FORWARD LINK)		DATA	18	A
DATA	101.1	INOPERATIVE FORWARD LINK	KA-BAND MODEM	DATA	19	A
DATA	101.2	DEGRADED FORWARD LINK	KA-BAND MODEM	DATA	20	A
DATA	102.0	KA-BAND MODEM GROUP (REPORT-BACK LINK)		DATA	21	A
DATA	102.1	INOPERATIVE REPORT-BACK LINK	KA-BAND MODEM	DATA	22	A
DATA	102.2	DEGRADED REPORT-BACK LINK	KA-BAND MODEM	DATA	23	A
DATA	103.0	KA-BAND MODEM GROUP (CONFERENCE LINK)		DATA	24	A
DATA	103.1	INOPERATIVE CONFERENCE LINK	KA-BAND MODEM	DATA	25	A
DATA	103.2	DEGRADED CONFERENCE LINK	KA-BAND MODEM	DATA	26	A
DATA	104.0	KA-BAND MODEM GROUP (SYSTEM INITIALIZATION)		DATA	27	A
DATA	104.1	UNABLE TO START SYSTEM	KA-BAND MODEM	DATA	28	A
DATA	104.2	ALTERNATE INITIALIZATION MODE REQUIRED	KA-BAND MODEM	DATA	29	A
DATA	106.0	KA-BAND MODEM GROUP (CONFERENCE AND REPORT-BACK COMMON FUNCTIONS)		DATA	32	A
DATA	106.1	CONFERENCE AND REPORT-BACK LINKS INOPERATIVE	KA-BAND MODEM	DATA	33	A
DATA	106.2	CONFERENCE AND REPORT-BACK LINKS DEGRADED	KA-BAND MODEM	DATA	34	A
DATA	4.0	SATCOM TERMINAL (PRIMARY POWER)		DATA	38	A
DATA	4.1	PRIMARY POWER FAILURE		DATA	39	A
DATA	111.0	KA-BAND INPUT/OUTPUT (FORWARD LINK)		DATA	40	A
DATA	111.1	NO/INCORRECT FORWARD LINK INPUT AND OUTPUT	KA-BAND I/O	DATA	41	A
DATA	111.2	NO/INCORRECT FORWARD LINK INPUT	KA-BAND I/O	DATA	42	A
DATA	111.3	NO/INCORRECT FORWARD LINK OUTPUT	KA-BAND I/O	DATA	43	A
DATA	112.0	KA-BAND INPUT/OUTPUT (REPORT-BACK LINK)		DATA	44	A
DATA	112.1	NO/INCORRECT REPORT-BACK OUTPUT	KA-BAND I/O	DATA	45	A
DATA	112.2	DEGRADED REPORT-BACK OUTPUT	KA-BAND I/O	DATA	46	A
DATA	113.0	KA-BAND INPUT/OUTPUT (CONFERENCE LINK)		DATA	47	A
DATA	113.1	NO CONFERENCE TTY AND VOICE	KA-BAND I/O	DATA	48	A
DATA	113.2	DEGRADED CONFERENCE LINK INPUT/OUTPUT	KA-BAND I/O	DATA	49	A
DATA	118.0	PAPER-TAPE READER		DATA	58	A
DATA	118.1	PAPER-TAPE READER MALFUNCTION		DATA	59	A
DATA	12.0	ANTENNA ALIGNMENT		DATA	62	A
DATA	12.1	NO OK-227 RANGE AND/OR RANGE RATE	ANT ALIGNMENT	DATA	63	A
DATA	121.0	AZIMUTH/RANGE BUFFER	APU-01	DATA	64	A
DATA	121.1	NO OK-227 RANGE (LAB: NO SSMP ANTENNA POINTING)	APU-01	DATA	65	A
DATA	122.0	ELEVATION/RANGE BUFFER	APU-02	DATA	66	A
DATA	122.1	NO OK-227 RANGE RATE (LAB: NO SSMP ANTENNA POINTING)	APU-02	DATA	67	A

values are printed. Setting the third logical variable to .TRUE. causes the analysis tables to be recorded and if the fourth logical variable is .TRUE., the percentage contribution tables will be recorded.

The ATTR Weighting Factor is used by the program whenever the calculations involve states incuding more than one malfunction. In such cases, the largest of the pertinent restore times is extended by a portion of the sum of the other pertinent restore times. If the value of the Weighting Factor is zero, only the longest of the pertinent restore times is used. A Weighting Factor value of 1.0 will cause the sum of the pertinent restore times to be employed in the calculations. Intermediate values of the Weighting Factor will cause a corresponding portion of the summed restore times to be used. The first card of Table A-1 illustrates the control card format for the case where some of the outputs are required and the value of the ATTR Weighting Factor is 0.8.

<u>Assembly Identification and Functional State Definition (Table A-1).</u>

The second data record consists of identification of all the elements, subassemblies and assemblies in the system and definitions of their functional states. The cards may be in any order, but it is recommended that the numeric sequence be retained within cards for a given functional block. The first three columns of each card are the identification numbers assigned for the element, subassembly or assembly; the fourth column is a decimal point; and the fifth column is the state number in the range from 0 to 8. State number 0 is used to

denote the element, subassembly and assembly identifications. The alphanumeric identification corresponding to the numeric identification appeai,s in columns 11 through 80.

Element Data (Table A-2). Data Record THREE contains the input data for the analysis elements in the form of MTBF and MTTR values for each malfunction and failure state. If the number of element states (column 5) is greater than 4, the MTBF and MTTR values are continued on a second card starting in column 16. The element number must be repeated on this card in columns 1-3 and 76-78 and the sequence number 12 is punched in columns 79-80. Example: TASA Nr. 108.

System Functional Model (Table A-3). Data Record Four must contain an entry for each nonelemental assembly in the system. Each such entry will consist of two or more cards. The first card describes the characteristics of the assembly. The model data for the assembly is entered, starting with the second card. This data consists of the consequence assignments from the TASA Work Sheets. There may be up to 697 such assignments, depending upon the number of input malfunction or failure states. These data are entered with 25 values per card (26 for the first card).

TASA/DEPEND ANALYSIS DEMONSTRATION

In the following pages, example computer printouts are given, presenting results of the analysis for the Ka-Band SATCOM Set. These analyses are based on data obtained from the results presented in AFAL-TR-78-135 and AFAL-TR-78-45 [14], [3].

Element Data Listings. Several types of outputs relating to the element

TABLE A-2   DATA RECORD THREE

MASTEF AUDIT, IDENT CARD TOTAL   UPDATE 1.3-476.   05/22/79 22.58.39.   PAGE

LIST OF CONTROL, ACTIVE, AND/OR INACTIVE CARDS IN DATA

DATA	000												DATA		365	A
DATA	4	1		136000	1.155E+03	1.0							401	2	27	A
DATA	14	1	1	4.2	5.177E+02	1.0							1401	2	28	A
DATA	021	1	1	600.	1.175E+02	1.0							2101	2	29	A
DATA	022	1	1	600.	1.198E+02	0.5							2201	2	30	A
DATA	040	2	1	4.2	872.0	1.75	28150.0	2.0					04001	2	31	A
DATA	31	1	1	4.2	1647.67	1.0							3101	2	32	A
DATA	32	2	1	4.2	1927.42	2.17	13790.1	0.5					3201	2	33	A
DATA	33	1	1	4.2	726.18	0.76							3301	2	34	A
DATA	034	3	1	4.2	3028.0	1.0	4570.0	1.0	13000.0	0.5			03401	2	35	A
DATA	035	3	1	4.2	1696.0	1.0	1350.0	3.42	5110.0	2.0			03501	2	36	A
DATA	031	1	1	4.2	1698.0	7.0							03101	2	37	A
DATA	095	1	1	4.2	1200.0	1.0							09501	2	38	A
DATA	101	2	1	4.2	661.3	0.90	2599.0	0.98					10101	2	39	A
DATA	102	2	1	4.2	1028.0	0.5	551.0	1.0					10201	2	40	A
DATA	103	2	1	4.2	1390.1	0.5	593.1	0.99					10301	2	41	A
DATA	108	8	1	4.2	539.76	0.5	67487000.	0.9	48347.9	0.5	1871.1	0.5	10801	2	42	A
DATA	108			4.2	500.0	0.5	12541.3	0.5	1128.01	1.97	10401.7	0.5	10802	2	43	A
DATA	118	1	1	300.	1.000E+03	0.5							11801	2	44	A
DATA	121	1	1	600.	1.830E+05	0.5							12101	2	45	A
DATA	122	1	1	600.	1.282E+04	0.5							12201	2	46	A
DATA	166	2	1	60.	5.000E+03	0.5	5.000E+03	0.5					16601	2	47	A

TABLE A-3 DATA RECORD FOUR

```
                 MASTER AUDIT, IDENT CARD TOTAL          UPDATE 1.3-476.     05/22/79  22.58.39.    PAGE

        LIST OF CONTROL, ACTIVE, AND/OR INACTIVE CARDS IN DATA
DATA    0000.00000                                                DATA    449   A
DATA     20 1     1 600. 2 2 21 22                         2001   DATA    450   A
DATA    0111                                               2002   DATA    451   A
DATA     12 1     1 600. 2 2121122                         1201   DATA    452   A
DATA    0111                                               1202   DATA    453   A
DATA    104 2     1350.0 3 2118166                        10401   DATA    456   A
DATA    02191119                                          10402   DATA    457   A
DATA    147 1   85   4.2 1 1 14                           14701   DATA    469   A
DATA    01                                                14702   DATA    470   A
DATA    209 2     1660.  5 4 20 12104147                  20901   2        48   A
DATA    31310193212121901011192121                        20902   2        49   A
DATA    200 8     1  4.215 2118 39                        20001   DATA    509   A
DATA    067959994599399349999999399                       20002   DATA    510   A
DATA    *2993993939999991 99999999                        20003   DATA    511   A
DATA    *99399939939998349299409393                       20004   DATA    512   A
DATA    *99992999319999974795994                          20005   DATA    513   A
DATA    *9333999329999913999933999                        20006   DATA    514   A
DATA    *9993605319933999399919939                        20007   DATA    515   A
DATA    *9199999999999999939999333                        20008   DATA    516   A
DATA    *52939599299919993299399199                       20009   DATA    517   A
DATA    *99999399990399999999999999                       20010   DATA    518   A
DATA    *99999444929949999333999239                       20011   DATA    519   A
DATA    *999199999999399999999999499                      20012   DATA    520   A
DATA    *999999939979999399999999933                      20013   DATA    521   A
DATA    *3919939 9939999199999919999                      20014   DATA    522   A
DATA    *99999999999999999999399939                       20015   DATA    523   A
DATA    *9939999939399939999999999                        20016   DATA    524   A
DATA    *9922292 392 9991999929999991                     20017   DATA    525   A
DATA    *99999999999999999999999999                       20018   DATA    526   A
DATA    *99399939993999999999999999                       20019   DATA    527   A
DATA    *99999993999399999999911919                       20020   DATA    528   A
DATA    *91999199991999991 99999999                       20021   DATA    529   A
```

data are printed by the computer. These are: input card images, numerical list of elements processed, and optional listings of processed element data. To provide a record of the element data used in the DEPEND run and to aid in the correction of errors or changing of input data, a card image listing of the element data record is printed. An example of this output is shown in Table A-2 and A-4. Also, in Table A-4, MTBF and MTTR values for various RUNS are given. By setting the second field of the output control card to .TRUE., two listings are ordered by increasing the numeric label and including the element identifications and the functional state definitions. Also included are the data for the number of functional cycles and use time per functional cycle. The first listing documents the MTBF and MTTR values. An example of this listing is shown in Table A-5. The second listing shows the calculated values of reliability and availability based on these data. An example of this output is shown in Table A-6.

Input Data Tabulation. The input data tabulation (Table A-5) lists the ELEMENT LABEL, which is an identification number for each element followed by a listing of the DATA IDENTIFICATION, which describes each data element. The elements include functional blocks of the system and the various possible states of malfunction or failure of these blocks, as used in the analysis. The functional blocks can be readily identified, because the element label number associated with them has a zero following the decimal point. Thus, element label 035.0 is the Ka-Band transmission subgroup. The various malfunction states for the Ka-Band transmission are then listed under element label 035.0, but with various numbers following the decimal

TABLE A-4 ELEMENT DATA INPUT FOR VARIOUS RUNS

```
ELEMENT DATA INPUT
  4 1    136000 1.155E+13 1.0                                             401
 14 1     1 4.2  5.177E+02 1.0                                            1401
021 1     1 600. 1.175E+02 1.0                                            2101
022 1     1 600. 1.198E+02 0.5                                            2201
040 2     1 4.2   332.0    1.752815u.0   2.0                             04001
 31 1     1 4.2  1647.67   1.0                                            3101
 32 2     1 4.2  1927.42   2.17 13790.1  0.5                              3201
 33 1     1 4.2   726.08   0.76                                           3301
034 3     1 4.2  3028.0    1.0   4570.0  1.0 10000.0  0.5                03401
035 3     1 4.2  1696.0    1.0   1350.0  3.42 5110.0  2.0                03501
091 1     1 4.2  1898.0    3.0                                           09101
095 1     1 4.2  1200.0    1.0                                           09501
101 2     1 4.2   881.3    0.98  2599.0  0.98                            10101
102 2     1 4.2  1028.0    0.5    551.0  1.0                             10201
103 2     1 4.2  1390.1    0.5    593.1  0.99                            10301
108 8     1 4.2   539.76   0.5  67487000. 0.9   48347.9  0.5  1871.1  0.5 10801
108         4.2   500.0    0.5 12541.3   0.5    1126.01 1.97 10401.7  0.5 10802
118 1     1 300. 1.000E+03 0.5                                           11801
121 1     1 600. 1.830E+05 0.5                                           12101
122 1     1 600. 1.282E+04 0.5                                           12201
166 2     1  60. 5.000E+03 0.5   5.000E+03 0.5                           16601
```

ELEMENT 035 AND ELEMENT 081

RUN ONE	MTBF X 1.0
RUN TWO	MTBF X 1.3
RUN THREE	MTBF X 1.5
RUN FOUR	MTBF X 1.7
RUN FIVE	MTBF X 2.0
RUN SIX	MTBF X 2.5
RUN SEVEN	MTBF X 3.0
RUN EIGHT	MTBF X 1.0 MTTR = 1.0

TABLE A-5 ELEMENT DATA LABEL IDENTIFICATION, MTBF AND MTTR

ELEMENT DATA LABEL	IDENTIFICATION		CYCLES	USE,SEC	MTBF,HRS	MTTR,HRS
4.0	SATCOM TERMINAL (PRIMARY POWER)			136000.000		
4.1	PRIMARY POWER FAILURE				.11550E+04	1.00
14.0	ROLM 1602 COMPUTER		1	4.200		
14.1	CPU STOP: NO UPLINK, PRINTER AND CRT EXCEPT FND. LINK OR CINCNET				.51770E+03	1.00
21.0	INERTIAL NAVIGATION SYSTEM		1	600.000		
21.1	NO/INCORRECT INS DATA	INS			.11750E+03	1.00
22.0	COMMUNICATIONS CONTROL COMPUTER		1	600.000		
22.1	NO/INCORRECT RANGE AND RANGE-RATE DATA	COMP. CONT. COMP.			.11980E+03	.50
31.0	COMMUNICATIONS TERMINAL POWER		1	4.200		
31.1	COMMUNICATIONS TERMINAL POWER FAILURE				.16477E+04	1.00
32.0	HEAT EXCHANGING		1	4.200		
32.1	NO HEAT EXCHANGING				.19274E+04	2.17
32.2	DEGRADED HEAT EXCHANGING				.13790E+05	.50
33.0	FREQUENCY GENERATION		1	4.200		
33.1	NO/INCORRECT FREQUENCY GENERATION				.72608E+03	.75
34.0	KA-BAND RECEPTION		1	4.200		
34.1	AUTO-TRACK RECEIVER FAILURE				.30260E+04	1.00
34.2	NO KA-BAND RECEPTION				.45700E+04	1.00
34.3	DEGRADED KA-BAND RECEPTION				.10000E+05	.50
35.0	KA-BAND TRANSMISSION		1	4.200		
35.1	DEGRADED RF POWER OUTPUT (50 WATTS MAX)	KA-BAND TRANSMISSION			.16960E+04	1.00
35.2	INSUFFICIENT RF POWER OUTPUT (LESS THAN 100 MW)	KA-BAND TRANSMISSION			.13500E+04	3.42
35.3	NO/INCORRECT DOPPLER CORRECTION	KA-BAND TRANSMISSION			.51100E+04	2.00
40.0	ANTENNA CONTROL GROUP (KA-BAND)		1	4.200		
40.1	NO KA-BAND TRANSMISSION AND RECEPTION	ANT CONT GRP			.83200E+03	1.75
40.2	DEGRADED KA-BAND TRANSMISSION AND RECEPTION	ANT CONT GRP			.28150E+05	2.00
81.0	KA BAND HPA		1	4.200		
81.1	KA BAND HPA INOPERATIVE				.18990E+04	3.00
85.0	KA BAND LNA		1	4.200		
85.1	KA BAND LNA INOPERATIVE				.12000E+04	1.00
101.0	KA-BAND MODEM GROUP (FORWARD LINK)		1	4.200		
101.1	INOPERATIVE FORWARD LINK	KA-BAND MODEM			.89130E+03	.90
101.2	DEGRADED FORWARD LINK	KA-BAND MODEM			.25990E+04	.98
102.0	KA-BAND MODEM GROUP (REPORT-BACK LINK)		1	4.200		
102.1	INOPERATIVE REPORT-BACK LINK	KA-BAND MODEM			.10280E+04	.50
102.2	DEGRADED REPORT-BACK LINK	KA-BAND MODEM			.55100E+03	1.00
103.0	KA-BAND MODEM GROUP (CONFERENCE LINK)		1	4.200		
103.1	INOPERATIVE CONFERENCE LINK	KA-BAND MODEM			.13900E+04	.50
103.2	DEGRADED CONFERENCE LINK	KA-BAND MODEM			.59310E+03	.99
108.0	KA-BAND MODEM GROUP (COMMON FUNCTIONS)		1	4.200		
108.1	ALL KA-BAND LINKS INOPERATIVE				.53976E+03	.50
108.2	FORWARD AND CONFERENCE LINKS INOPERATIVE AND R/B LINK DEGRADED				.67487E+06	.90
108.3	R/B AND CONFERENCE LINKS INOPERATIVE AND FORWARD LINK DEGRADED				.48348E+05	.50
108.4	ALL KA-BAND LINKS DEGRADED				.18711E+04	.50
108.5	KA-BAND FORWARD AND CONFERENCE LINKS INOPERATIVE				.50000E+03	.50
108.6	KA-BAND REPORT-BACK AND CONFERENCE LINKS INOPERATIVE				.12541E+05	.50
108.7	KA-BAND FORWARD AND CONFERENCE LINKS DEGRADED				.11290E+04	1.97
108.9	KA-BAND REPORT-BACK AND CONFERENCE LINKS DEGRADED				.10402E+05	.50
118.0	PAPER-TAPE READER		1	300.000		
118.1	PAPER-TAPE READER MALFUNCTION				.10000E+04	.50
121.0	AZIMUTH/RANGE BUFFER	APU-01	1	600.000		
121.1	NO OK-227 RANGE (LAB: NO SSMF ANTENNA POINTING)	APU-01			.18300E+06	.50

TABLE A-6 ELEMENT DATA LABEL IDENTIFICATION, RELIABILITY AND AVAILABILITY

ELEMENT DATA LABEL	IDENTIFICATION		CYCLES	USE,SEC	RELIABILITY	AVAILABILITY	MTTR,HRS
4.0	SATCOM TERMINAL (PRIMARY POWER)			136000.000	.991379E+00	.999135E+00	
4.1	PRIMARY POWER FAILURE				.862064E-02	.865426E-03	1.000
14.0	FOLM 1602 COMPUTER		1	4.200	.999998E+00	.998070E+00	
14.1	CPU STOP: NO UPLINK, PRINTER AND CRT EXCEPT FWD. LINK OR CINCNET				.225355E-05	.192976E-02	1.000
21.0	INERTIAL NAVIGATION SYSTEM		1	600.000	.998583E+00	.991525E+00	
21.1	NO/INCORRECT INS DATA	INS			.141743E-02	.847453E-02	1.000
22.0	COMMUNICATIONS CONTROL COMPUTER		1	600.000	.998610E+00	.995835E+00	
22.1	NO/INCORRECT RANGE AND RANGE-RATE DATA	COMM. CONT. COMP.			.139024E-02	.416493E-02	.500
31.0	COMMUNICATIONS TERMINAL POWER		1	4.200	.999999E+00	.999393E+00	
31.1	COMMUNICATIONS TERMINAL POWER FAILURE				.708070E-06	.606734E-03	1.000
32.0	HEAT EXCHANGING		1	4.200	.999399E+00	.998839E+00	
32.1	NO HEAT EXCHANGING				.605299E-06	.112522E-02	2.170
32.2	DEGRADED HEAT EXCHANGING				.646018E-07	.362572E-04	.500
33.0	FREQUENCY GENERATION		1	4.200	.999998E+00	.998954E+00	
33.1	NO/INCORRECT FREQUENCY GENERATION				.160680E-05	.104617E-02	.760
34.0	KA-BAND RECEPTION		1	4.200	.999999E+00	.999401E+00	
34.1	AUTO-TRACK RECEIVER FAILURE				.385293E-06	.330196E-03	1.000
34.2	NO KA-BAND RECEPTION				.255268E-06	.218794E-03	1.000
34.3	DEGRADED KA-BAND RECEPTION				.116667E-06	.499958E-04	.500
35.0	KA-BAND TRANSMISSION		1	4.200	.999998E+00	.996469E+00	
35.1	DEGRADED RF POWER OUTPUT (50 WATTS MAX)	KA-BAND TRANSMISSION			.687893E-06	.569449E-03	1.000
35.2	INSUFFICIENT RF POWER OUTPUT (LESS THAN 100 MW)	KA-BAND TRANSMISSION			.864197E-06	.253013E-02	3.420
35.3	NO/INCORRECT DOPPLER CORRECTION	KA-BAND TRANSMISSION			.225310E-06	.391313E-03	2.000
40.0	ANTENNA CONTROL GROUP (KA-BAND)		1	4.200	.999999E+00	.997528E+00	
40.1	NO KA-BAND TRANSMISSION AND RECEPTION	ANT CONT GRP			.140224E-05	.210115E-02	1.750
40.2	DEGRADED KA-BAND TRANSMISSION AND RECEPTION	ANT CONT GRP			.414446E-07	.710454E-04	2.000
81.0	KA BAND HPA		1	4.200	.999999E+00	.998421E+00	
81.1	KA BAND HPA INOPERATIVE				.614682E-06	.157936E-02	3.000
95.0	KA BAND LNA		1	4.200	.999999E+00	.999167E+00	
95.1	KA BAND LNA INOPERATIVE				.972222E-06	.832986E-03	1.000
101.0	KA-BAND MODEM GROUP (FORWARD LINK)		1	4.200	.999998E+00	.998602E+00	
101.1	INOPERATIVE FORWARD LINK	KA-BAND MODEM			.132380E-05	.102070E-02	.900
101.2	DEGRADED FORWARD LINK	KA-BAND MODEM			.448891E-06	.376997E-03	.900
102.0	KA-BAND MODEM GROUP (REPORT-BACK LINK)		1	4.200	.999997E+00	.997701E+00	
102.1	INOPERATIVE REPORT-BACK LINK	KA-BAND MODEM			.113489E-05	.466263E-03	.500
102.2	DEGRADED REPORT-BACK LINK	KA-BAND MODEM			.211736E-05	.161324E-02	1.000
103.0	KA-BAND MODEM GROUP (CONFERENCE LINK)		1	4.200	.999997E+00	.997973E+00	
103.1	INOPERATIVE CONFERENCE LINK	KA-BAND MODEM			.839260E-06	.359622E-03	.500
103.2	DEGRADED CONFERENCE LINK	KA-BAND MODEM			.196716E-05	.165780E-02	.900
108.0	KA-BAND MODEM GROUP (COMMON FUNCTIONS)		1	4.200	.999994E+00	.995964E+00	
108.1	ALL KA-BAND LINKS INOPERATIVE				.216145E-05	.925909E-03	.500
108.2	FORWARD AND CONFERENCE LINKS INOPERATIVE AND R/B LINK DEGRADED				.172875E-10	.133359E-07	.900
108.3	R/B AND CONFERENCE LINKS INOPERATIVE AND FORWARD LINK DEGRADED				.241307E-07	.103417E-04	.500
108.4	ALL KA-BAND LINKS DEGRADED				.623519E-06	.267167E-03	.500
108.5	KA-BAND FORWARD AND CONFERENCE LINKS INOPERATIVE				.233333E-05	.999500E-03	.500
108.6	KA-BAND REPORT-BACK AND CONFERENCE LINKS INOPERATIVE				.930263E-07	.398675E-04	.500
108.7	KA-BAND FORWARD AND CONFERENCE LINKS DEGRADED				.103427E-05	.174491E-02	1.970
108.8	KA-BAND REPORT-BACK AND CONFERENCE LINKS DEGRADED				.112161E-06	.480679E-04	.500
116.0	PAPER-TAPE READER		1	300.000	.999917E+00	.999500E+00	
116.1	PAPER-TAPE READER MALFUNCTION				.833299E-04	.499875E-03	.500
121.0	AZIMUTH/RANGE BUFFER	APU-01	1	600.000	.999999E+00	.999997E+00	
121.1	NO OK-227 RANGE (LAB: NO SSMP ANTENNA POINTING)	APU-01			.910746E-06	.273224E-05	.500

point. Element label number 35.1, for example, and its associated data identification, "Degraded RF Power Output (50 watt max.)" provided the information that the transmission subgroup was in a degraded state at the elemental level.

The column headed CYCLES contains a 1 or a 0, indicating that the functional block listed is or is not used during the mission for which the specific analysis is being performed.

The column headed USE,SEC lists the number of seconds required to complete one functional cycle of the subject functional block. Thus element 4.0, the SATCOM Terminal (Primary Power), for example, is used for 36,000 seconds; that is, for the entire ten hours of the mission described in the main body of this report. The functional cycle duration for most functional blocks is 4.2 seconds, although there are several exceptions.

The column labelled MTBF, HRS, lists the MTBF associated with that assembly or malfunction, in hours (It should be remembered that these figures constitute an input to the computer program). This column, and the last column (MTTR,HRS), at the basic building block level, contain data generated during flight test, received from manufacturers, etc.. The results obtained for the higher functional levels are based on the data for the basic building block level.

ANALYSIS SCHEDULE

The actual operation of the DEPEND program is to perform the computations for each functional assembly separately once all the necessary input data are available. Prior to the start of any computations, a scheduling routine is used to determine the order in

which the computations will be performed. This routine prints the resultant analysis schedule, showing the elements/subassemblies used by each assembly and the next assemblies to use the results obtained. Since the order of the printed results are in the order in which computations are performed, this Analysis Schedule is an index to the results and to the State Assignment Listing described above. An example Analysis Schedule is shown in Table A-7.

ANALYSIS SUMMARY

The results of the DEPEND calculations are output in both tabular and statement form. A title page is provided to document the date and time of the DEPEND run and the title of the analysis. An example title page is shown in Figure A-1.

Tabular Summary of Results. The results of the "ility" computations for each functional assembly are printed in an Analysis Summary on one page of the computer output. An example Analysis Summary is shown in Table A-8. At the top of the summary, the assembly is identified together with the other assemblies which use it, if any.

Next are listed the subassembly or element state data employed in terms of the probability of state occurrence during use (unreliability) and unavailability. The entry, ENT, following the label denotes an element, while CMP denotes a subassembly. The number of functional cycles, the time used per cycle and the average restore time are also listed. Note that the unreliabilities and unavailabilities for the assembly functional states are only printed in the Analysis Summary for the next level assembly where it is used. In

TABLE A-7 KaBand SATCOM SET TRUNCATED MODEL (MODIFIED) ANALYSIS SCHEDULE

ANALYSIS SCHEDULE

ITERATION	ELEMENTS/SUBASSEMBLIES							ASSEMBLY	NEXT ASSEMBLIES			
1	21	22						20	209			
2	121	122						12	209			
3	118	166						104	209			
4	14							147	209			
5	20	12	104	147				209	6	7	8	2
6	101							215	205			
7	215							205	208			
8	102							216	206			
9	216							206	208			
10	103							217	207			
11	217							207	208			
12	31	32	33	34	35	95	81	38	39			
13	40	38						39	200			
14	100	39						200	211	212	213	204
15	14	200	101					211	201			
16	211							201	6			
17	14	200	102					212	202			
18	212							202	7			
19	14	200	103					213	203			
20	213							203	8			
21	14	200						204	208			
22	204	205	206	207				208	2			
23	4	209	201					6	0			
24	4	209	202					7	0			
25	4	209	203					8	0			
26	4	209	208					2	0			

ITERATIONS END

```
*D E P E N D*

(D)ETERMINATION OF (E)QUIPMENT (P)ERFORMANCE (E)XPECTATION AND (N)ONOPERATIONAL (D)ELAY

(TASPA VERSION IV - 5/10/78)

AFAL/AAD-1 SATELLITE COMMUNICATIONS GROUP  WRIGHT-PATTERSON AFB, OH

AFAL-TR-78-135, Part 3 "USER'S MANUAL"

DEVELOPED BY BATTELLE-COLUMBUS LABORATORIES

05/22/79

22.59.16.

RUN FIVE   30108   2.0
           KA-BAND SATCOM SET
            PROGRAM DEPEND
               MODIFIED
            TRUNCATED MODEL
```

FIGURE A-1

TITLE PAGE FOR RUN FIVE

TABLE A-8 EXAMPLE -- RUN FIVE ANALYSIS SUMMARY

A N A L Y S I S   S U M M A R Y

FOR ASSEMBLY NUMBER 38

KA-BANK TERMINAL GROUP

ASSEMBLY 38 IS USED BY ASSEMBLY(S) 39

SUBASSEMBLY STATE DATA

LABEL		NO. OF CYCLES	TIME OF USE,SEC	PROB. OF OCCURRENCE	RESTORE TIME,HRS	SUBASSEMBLY UNAVAILABILITY	IDENTIFICATION	
31.1	ENT	1	4.20	.70807E-06	1.00	.60673E-03	COMMUNICATIONS TERMINAL POWER FAILURE	
32.1	ENT	1	4.20	.605305E-06	2.17	.11292E-02	NO HEAT EXCHANGING	
32.2	ENT	1	4.20	.84602E-07	.50	.36257E-04	DEGRADED HEAT EXCHANGING	
33.1	ENT	1	4.20	.16068E-05	.76	.10462E-02	NO/INCORRECT FREQUENCY GENERATION	
34.1	ENT	1	4.20	.38529E-06	1.00	.33020E-03	AUTO-TRACK RECEIVER FAILURE	
34.2	ENT	1	4.20	.25529E-06	1.00	.21879E-03	NO KA-BAND RECEPTION	
34.3	ENT	1	4.20	.11667E-06	.50	.49999E-04	DEGRADED KA-BAND RECEPTION	
35.1	ENT	1	4.20	.68769E-06	1.00	.58945E-03	DEGRADED RF POWER OUTPUT (50 WATTS MAX)	KA-BAND TRANSMISSION
35.2	ENT	1	4.20	.86420E-06	3.42	.25301E-02	INSUFFICIENT RF POWER OUTPUT (LESS THAN 100 MW)	KA-BAND TRANSMISSION
35.3	ENT	1	4.20	.22831E-06	2.00	.39131E-03	NO/INCORRECT DOPPLER CORRECTION	KA-BAND TRANSMISSION
95.1	ENT	1	4.20	.97222E-06	1.00	.83299E-03	KA BAND LNA INOPERATIVE	
81.1	ENT	1	4.20	.61468E-06	3.00	.15794E-02	KA BAND HPA INOPERATIVE	

A S S E M B L Y   S T A T E S

STATE	PROBABILITY	ATBD, HRS.	ATTR, HRS.	IDENTIFICATION
0	.9906933394			NORMAL OPERATION
1	.276079E-02	3.93522E+02	1.385	NO KA-BAND TRANSMISSION AND RECEPTION
2	.573300E-06	2.37982E+09	3.183	NO KA-BAND TRANSMISSION AND DEGRADED RECEPTION
3	.115477E-02	8.59418E+02	1.000	NO KA-BAND RECEPTION
4	.367863E-04	1.37901E+04	.573	DEGRADED
5	.215366E-02	8.95667E+02	2.457	NO KA-BAND TRANSMISSION
6	.290185E-02	1.06769E+03	3.230	DEGRADED KA-BAND TRANSMISSION
7	.266710E-03	3.13660E+03	.907	DEGRADED KA-BAND RECEPTION
8	.319122E-04			OTHER STATES
COMBINED		1.63643E+02	2.139	

ASSEMBLY 38 OPERATES FOR 4.200 SECONDS TO COMPLETE ITS FUNCTION.
THE AVAILABILITY IS .9907004024, RELIABILITY IS .9999928707 AND DEPENDABILITY IS .9906933394.
9.31 MALFUNCTIONS ARE EXPECTED TO OCCUR DURING 1000 FUNCTIONAL CYCLES
AND A DELAY OF 64.21 MINUTES IS EXPECTED WHEN A MALFUNCTION OCCURS.

AD-A076 163 AIR FORCE AVIONICS LAB WRIGHT-PATTERSON AFB OH F/G 17/2.1
SATCOM 'EHF' AIRBORNE TERMINAL AVAILABILITY TO COST ANALYSIS DE--ETC(U)
JUL 79 H M BARTMAN
UNCLASSIFIED AFAL-TR-79-1105 NL

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the case where the assembly is a top level one, a separate listing is printed on the next page to record the "ility" data and the undependability, unreliability and unavailability for each non-normal state. An example of such a System Data listing is shown in Table A-9.

Referring again to Table A-8, the second part of the Analysis Summary records the probabilities of occurrence of each functional state defined for the assembly. The probability of normal operation is the dependability, while the probabilities of occurrence of the other functional states are the corresponding undependabilities. An extra "residual" state is included to account for the occurrence of states not explicitly defined, including those cases of four or more simultaneous state occurrences. Included in this part of the summary are calculated predictions of the average time between occurrences of the non-normal states and the average time to restore normal operation after such an occurrence.

The combined prediction for ATBO expresses the average time between occurrences of any of the non-normal states. The combined ATTR is the average restore time, taking into account the probability of occurrence of each non-normal state.

Statement of Results At the bottom of each Analysis Summary is printed a statement summarizing the operation, "ility" results, expected number of occurrences of non-normal states, and the delay that the system user is expected to experience in case of a malfunction.

Functional Model Data Listings

The DEPEND Program output includes two types of listings to document the functional model data. These are a listing of input card

TABLE A-9

EXAMPLE OF ESTIMATED VALUES OF AVAILABILITY, RELIABILITY AND DEPENDABILITY

SYSTEM DATA FOR RUN FIVE

S Y S T E M   D A T A

2 KA-BAND SATCOM SET (SUMMARY)

LABEL	AVAILABILITY	RELIABILITY	DEPENDABILITY	IDENTIFICATION
2.0	.975032E+00	.828265E+00	.837598E+00	NORMAL OPERATION
2.1	.101986E-01	.665102E-01	.743295E-01	ALL KA-BAND LINKS INOPERATIVE
2.2	.103369E-02	.851F82E-02	.921712E-02	COMBINATION OF 1 (2) INOPERATIVE AND 2 (1) DEGRADED KA-BAND LINKS
2.3	.39723_-03	.451925E-02	.47388E-02	ALL KA-BAND LINKS DEGRADED
2.4	.237755E-02	.214928F-01	.23485E-01	TWO KA-BAND LINKS INOPERATIVE
2.5	.112911E-04	.912135E-03	.899932E-03	ONE INOPERATIVE AND ONE DEGRADED KA-BAND LINK
2.6	.467918E-02	.135477E-01	.172066E-01	TWO KA-BAND LINKS DEGRADED
2.7	.175015E-02	.165F02E-01	.198446E-01	ONE KA-BAND LINK INOPERATIVE
2.8	.369344E-02	.200652E-01	.285575E-01	ONE KA-BAND LINK DEGRADED
2.9	.195292E-03	.112958E-01	.141508E-01	OTHER STATES

images and an optional listing that reproduces the TASA work sheet format to show the details of the state combinations and consequence assignments. The listing of input card images from the model input deck documents the data used for the DEPEND run. It is a primary means of tracking down errors and debugging the model data. An example of this listing is shown in an earlier section. The system functional model (Table A-3) is actually documented in the TASA work sheets. Setting the third field of the output control card to .TRUE. causes the computer to reproduce the TASA data in tabular form. It provides a printed record of the TASA, including the identification of the elements, subassemblies and assemblies and the consequences determined for each combination of element/subassembly states for each assembly. As a general rule, once the model has been debugged and a finalized copy of this listing obtained, the listing will not be printed for runs made with updated element data. However, this listing does provide comprehensive documentation of the model structure and consequence assignments used for the DEPEND run. An example page of this State Assignment Listing is shown in Figure C-5 of Appendix C. The total listing for a system of any size is quite large. A title page is provided for the listing, so that it is an independent documentation of the model.

OPTIONAL SENSITIVITY TABULATIONS

When the fourth field of the output control card is set to .TRUE. in Table A-1, the DEPEND program will output the results of sensitivity calculations for each assembly.

Percentage Contribution Tabulations. The results of the sensitivity calculations are presented in terms of the percentage contribution of each element or subassembly state to the unavailability, unreliability and undependability for each defined assembly state. An example page of the output is shown in Table A-10. From this tabulation the relative importance of each element or subassembly state to the malfunctioning or failure of the assembly can be easily observed. This provides a rational basis for allocating resources to achieve improvement of the assembly. It also gives a basis for specifying "ility" requirements for the elements and subassemblies, to assure that the assembly meets it's "ility" goals.

Tracing System Sensitivity. The number of possible paths involved in tracing the percentage contribution to system undependabilities, reliabilities and unavailabilities makes using a computer routine for this purpose impractical. A large amount of output would be obtained for the large number of low or zero percentage paths which are not of interest. However, a simple calculator procedure has been developed that can be used to evaluate the significant percentage contribution of components to the system undependability, unreliability and unavailability.

The assembly sensitivity tabulations from the DEPEND program results are used in a top-down chain calculation, as discussed in Appendix D.

TABLE A-10 EXAMPLE OF SENSITIVITY TABULATION FOR ASSEMBLY 208 IN RUN FIVE

PERCENTAGE CONTRIBUTION TO ASSEMBLY 200 UNAVAILABILITY

ASSEMBLY STATE	SUBASSEMBLY AND/OR ELEMENT STATES															
	108.1	108.2	108.3	108.4	108.5	108.6	108.7	108.8	39.1	39.2	39.3	39.4	39.5	39.6	39.7	TOTAL
208.1	6.0	.0	.0	.0	.0	.0	.0	.0	31.4	.0	.0	.0	.0	.0	.0	37.5
208.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
208.3	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	7.4	.0	.0	.0	.0	7.5
208.4	.0	.0	.0	1.7	.0	.0	.0	.0	.0	.0	.0	.7	.0	.0	.0	2.4
208.5	.0	.0	.0	.0	6.5	.0	.0	.0	.0	.0	.0	.0	13.8	.0	.0	20.3
208.6	.0	.0	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.3
208.7	.0	.0	.0	.0	.0	.0	11.3	.0	.0	.0	.0	.0	.0	18.6	.0	30.0
208.8	.0	.0	.0	.0	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	1.7	2.0
TOTAL	6.0	.0	.1	1.7	6.5	.3	11.4	.3	31.4	.0	7.4	.7	13.8	18.7	1.7	

PERCENTAGE CONTRIBUTION TO ASSEMBLY 200 UNRELIABILITY

ASSEMBLY STATE	SUBASSEMBLY AND/OR ELEMENT STATES															
	108.1	108.2	108.3	108.4	108.5	108.6	108.7	108.8	39.1	39.2	39.3	39.4	39.5	39.6	39.7	TOTAL
208.1	14.7	.0	.0	.0	.0	.0	.0	.0	28.9	.0	.0	.0	.0	.0	.0	43.6
208.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
208.3	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	8.9	.0	.0	.0	.0	9.1
208.4	.0	.0	.0	4.2	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0	.0	5.1
208.5	.0	.0	.0	.0	15.8	.0	.0	.0	.0	.0	.0	.0	8.5	.0	.0	24.3
208.6	.0	.0	.0	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6
208.7	.0	.0	.0	.0	.0	.0	7.0	.0	.0	.0	.0	.0	.0	7.0	.0	14.1
208.8	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0	.0	.0	.0	.0	2.4	3.2
TOTAL	14.7	.0	.2	4.2	15.8	.6	7.0	.8	28.9	.0	8.9	.8	8.5	7.0	2.4	

PERCENTAGE CONTRIBUTION TO ASSEMBLY 200 UNDEPENDABILITY

ASSEMBLY STATE	SUBASSEMBLY AND/OR ELEMENT STATES															
	108.1	108.2	108.3	108.4	108.5	108.6	108.7	108.8	39.1	39.2	39.3	39.4	39.5	39.6	39.7	TOTAL
208.1	6.0	.0	.0	.0	.0	.0	.0	.0	31.4	.0	.0	.0	.0	.0	.0	37.5
208.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
208.3	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	7.4	.0	.0	.0	.0	7.5
208.4	.0	.0	.0	1.7	.0	.0	.0	.0	.0	.0	.0	.7	.0	.0	.0	2.4
208.5	.0	.0	.0	.0	6.5	.0	.0	.0	.0	.0	.0	.0	13.8	.0	.0	20.3
208.6	.0	.0	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.3
208.7	.0	.0	.0	.0	.0	.0	11.3	.0	.0	.0	.0	.0	.0	18.6	.0	29.9
208.8	.0	.0	.0	.0	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	1.7	2.0
TOTAL	6.0	.0	.1	1.7	6.5	.3	11.4	.3	31.4	.0	7.4	.7	13.8	18.7	1.7	

APPENDIX B

TASRA/TASA MODEL

The standard TASRA model discussed in AFAL-TR-78-135 has been modified by Battelle Columbus Laboratories (BCL) to provide availability and dependability information. The modified model was renamed Tabular Systems Analysis, TASA. The general mathematical model used for the combined availability/dependability analyses and predictions is described below. A primary objective of the development of this model by BCL has been to orient it toward the user. From the user's viewpoint, the performance of the Ka-Band SATCOM terminal, for example, is measured by its availability at the time the user needs to send or receive a message and its availability to meet a mission profile which defines the numbers of communications that must be completed for each alternative communications mode as functions of mission time. One specific measure employed is the dependability; that is, the probability that a specified number of communications will be initiated and completed without the occurrence of delay resulting from equipment malfunction. A second measure of terminal performance is "expected communication delay" which is defined as the "best estimate" of the delay in completing a communication that results if the equipment malfunctions. The relationships of dependability, (D), and expected communication delay, (ECD), to the reliability, availability, and operational usage of the functional assemblies of the system are described in the following mathematical development.

The following definitions were developed by Mr. James Drennan of (BCL) and presented in Reference 14.

(1) Reliability, R, is the probability that a specified function, which is initially in a normal operating state, will continue without malfunction for a specified length of time.

(2) Availability, A, is the probability that a specified function is in its normal operating state at a specified time.

(3) ATTR is the average time to restore a specified communication function after occurrence of a specified malfunction state by the use of a specified process of replacement, repair, or the utilization of degraded or alternate communication modes.

(4) ATBO is the average time between occurrences of a specified malfunction state.

The ATTR and ATBO are estimated at the elemental subassembly level of the system, by values of the mean restoration time (MTR) and mean time between failures (MTBF) respectively, that are determined by conventional reliability and maintainability approaches and provided as data input for the model. For the higher levels of the system hierarchy, the ATTR and ATBO values may be determined similarly to interpretation of MTR and MTBF values obtained from conventional reliability and maintainability analyses. However, the ATTR and ATBO parameters are more realistic and user oriented than their conventional courterparts.

Reliability is a conditional probability, the condition being that the specified equipment functions are initially in an operational state. It follows that the unconditional probability that the specified functions will be in their normal operating states at a specified time and will continue to operate without malfunction for a specified period is given by the product of availability and reliability. This is the dependability of one communication:

$$D = A \cdot R \quad . \tag{B-1}$$

The binomial distribution is used to express the probability that the specified functions will be dependable for each of a specified number, M, of independent trials. This is the mission dependability defined earlier and expressed as:

$$D(M) = A(M)R^{M} \quad . \tag{B-2}$$

It is postulated that a number, K, of malfunction states are defined in addition to normal operation for each functional assembly and subassembly of the Ka-Band terminal. Let $MTBF_{ijk}$ denote the specified value of the mean time between occurrence of the k^{th} malfunction type in the j^{th} elemental subassembly of the i^{th} functional assembly and MTR_{ijk} is the corresponding specified mean time to restore the communication capability. The term t_o is used to designate a time when it is desirable to initiate a communication that uses this subassembly. The subassembly is required to operate normally for a time, t_{ij}, to complete the communication. The Poisson distribution is used to express the subassembly reliability:

$$R_{ij} = \prod_{k=1}^{K} e^{-\frac{t_{ij}}{MTBF_{ijk}}} = e^{-t_{ij} \sum_{k=1}^{K} \left(\frac{1}{MTBF_{ijk}}\right)}, \qquad \text{(B-3)}$$

where K denotes the number of communications disrupting malfunction types that can occur in the j^{th} elemental subassembly.

The following additional definitions and subsequent mathematical developments were prepared by Mr. Drennan of BCL (Reference 14).

T_i = length of one functional cycle (mission) of the i^{th} assembly consisting of I elements.

t_{ij} = length of one use of the j^{th} element of the i^{th} assembly.

N_{ij} = number of uses of the j^{th} element during one functional cycle of the i^{th} assembly.

MRT_{ijk} = mean time to restore system operation following occurrence of the k^{th} type of failure or malfunction in the j^{th} element of the i^{th} assembly.

$ATBO_{ijk}$ = mean time between occurrence of the k^{th} failure or malfunction state of the j^{th} element of the i^{th} assembly

$$UA'_{ijk} = 1 - e^{-\frac{MRT_{ijk}}{ATBO_{ijk}}}$$

= initial unavailability of the j^{th} element of the i^{th} assembly associated with occurrence of the k^{th} type of failure or malfunction during an interval of duration MRT_{ijk}.

$$UR_{ijk} = 1 - e^{-\frac{N_{ij} t_{ij}}{ATBO_{ijk}}}$$

= unreliability of the jth element of the i^{th} assembly associated with the occurrence of the k^{th} type of failure or malfunction during N_{ij} uses.

The number of standby intervals prior to the N_{ij} uses of the $j^{\underline{th}}$ element of the $i^{\underline{th}}$ assembly is N_{ij}. Excluding the interval prior to the first use, average length of these intervals is $(T_i - N_{ij}t_{ij})/(N_{ij}-1)$. Hence, the probability of occurrence of the $k^{\underline{th}}$ failure or malfunction state of the $j^{\underline{th}}$ element during these standby intervals is the standby unavailability.

$$UAS_{ijk} = 1 - e^{-\left(\frac{T_i - N_{ij}t_{ij}}{ATBO_{ijk}}\right)} \quad ; \quad [(T_i - N_{ij}t_{ij})/(N_{ij} - 1)] < MRT_{ijk} \qquad \text{(B-4a)}$$

$$= 1 - e^{-\left[\frac{(N_{ij} - 1) \cdot MRT_{ijk}}{ATBO_{ijk}}\right]} \quad ;$$

$$[(T_i - N_{ij}t_{ij}/(N_{ij} - 1))] \geq MRT_{ijk} \qquad \text{(B-4b)}$$

The case of Equation B-4a considers an initial interval of length MRT_{ijk} and $(N_{ij} - 1)$ intervals between use. Equation B-4b results because the unavailability at a time earlier than one MRT_{ijk} before use is zero. In this case there are N_{ij} intervals of length MRT_{ijk} during which the occurrence of a failure or malfunction will affect the assembly availability.

The unreliability, UR_{ijk}, is the probability of occurrence of a failure or malfunction during an interval of duration, t_{ij}, and is related to the $ATBO_{ijk}$ by:

$$UR_{ijk} = 1 - e^{-\left(\frac{t_{ij}}{ATBO_{ijk}}\right)} \qquad \text{(B-5)}$$

Combining equations B-4 and B-5 gives an expression for the standby unavailability in terms of the unreliability:

$$UAS_{ijk} = 1 - (1-UR_{ijk})^{\left(\frac{T_i - N_{ij} t_{ij}}{t_{ij}}\right)} \quad ; \tag{B-6a}$$

$$[(T_i - N_{ij} t_{ij})/(N_{ij}-1)] < MRT_{ijk}$$

$$= 1 - (1-UR_{ijk})^{\left[\frac{(N_{ijk}-1)\cdot MRT_{ijk}}{t_{ijk}}\right]} \quad ; \tag{B-6b}$$

$$[(T_i - N_{ij} t_{ij})/(N_{ij}-1)] \geq MRT_{ijk}$$

Now the initial unavailability is defined as:

$$UAO_{ijk} = 1 - e^{-\frac{MRT_{ijk}}{MTBF_{ijk}}} \tag{B-7}$$

The combined unavailability is seen to be:

$$UA_{ijk} = 1 - [(1-UAO_{ijk}) \cdot (1-UAS_{ijk})]$$

$$= 1 - (1-UAO_{ijk})(1-UR_{ijk})^{\left[\frac{T_i - N_{ij} t_{ij}}{t_{ij}}\right]} \quad ; \tag{B-8a}$$

$$[(T_i - N_{ij} t_{ij})/(N_{ij}-1)] < MRT_{ijk}$$

$$= 1 - (1-UAO_{ijk})(1-UR_{ijk})^{\frac{[(N_{ij}-1)MRT_{ijk}]}{t_{ij}}} \quad ; \tag{B-8b}$$

$$[(T_i - N_{ij} t_{ij})/(N_{ij}-1)] \geq MRT_{ijk}$$

The values for unavailability and unreliability are combined to determine the undependability:

$$UD_{ijk} = UA_{ijk} + UR_{ijk} - (UA_{ijk} \cdot UR_{ijk}) \tag{B-9}$$

Whenever a malfunction or failure causes unavailability or unreliability, the time when the communication capability will be restored is seen to be a uniformly increasing function of the time when the malfunction or failure occurred. If the malfunction or failure occurs prior to the first use, the average delay is $(MRT_{ijk}/2)$. This is also the average delay for standby malfunctions or failures when the average separation between uses is equal to or greater than MRT_{ijk}. However, when the average use separation is less than MRT_{ijk}, the average delay resulting from a standby malfunction or failure is $[MRT_{ij}-(T_i-N_{ij}t_{ij})/2 \cdot (N_{ij}-1)]$. Finally, an average delay equal to MRT_{ijk} results from a malfunction or failure that occurs during use. Hence, the expected delay that will result from occurrence of the $k^{\underline{th}}$ type of malfunction or failure in the $j^{\underline{th}}$ element or subassembly of the $i^{\underline{th}}$ assembly is obtained from summing the products of occurrence probability and corresponding average delays:

$$\begin{aligned} EDLY = {} & UAO_{ijk}(MRT_{ijk}/2) \\ & + \left[1-(1-UR_{ijk})^{\frac{(T_i-N_{ij}t_{is})}{t_{ij}}}\right]\left[MRT_{ijk}-(T_i-N_{ij}t_{ij})/2(N_{ij}-1)\right] \\ & + UR_{ijk} \cdot MRT_{ijk} \quad ; \quad [(T_i-N_{kj}t_{ij})/(N_{ij}-1)] < MRT_{ijk} \end{aligned} \tag{B-10a}$$

$$\begin{aligned} = {} & \left[UAO_{ijk} + \left\{1-(1-UR_{ijk})^{\left[\frac{(N_{ij}-1)MRT_{ijk}}{t_{ij}}\right]}\right\}\right](MRT_{ijk}/2) \\ & + UR_{ijk} \cdot MRT_{kjk} \quad ; \quad [(T_i-N_{ij}t_{ij})/(N_{ij}-1)] \geq MRT_{ijk} \end{aligned} \tag{B-10b}$$

Considering the M^{th} combination of element states in the assembly analysis (i.e the m^{th} row of the TASRA table) the unavailability, unreliability and undependability of the combination are calculated by the TASRA algorithm:

$$UA_m = \prod_{j=1}^{J_i} \prod_{k=1}^{K_{ij}} \left[B_{ijk} UA_{ijk} + (1-B_{ijk}) \right] (1-UA_{ijk}) \tag{B-11a}$$

$$UR_m = \prod_{j=1}^{J_i} \prod_{k=1}^{K_{ij}} \left[B_{ijk} UR_{ijk} + (1-B_{ijk}) \right] (1-UR_{ijk}) \tag{B-11b}$$

$$UD_m = \prod_{j=1}^{J_i} \prod_{k=1}^{K_{ij}} \left[B_{ijk} UD_{ijk} + (1-B_{ijk}) \right] (1-UD_{ijk}) \tag{B-11c}$$

where $B_{ijk} = 1$ *if the TASRA table indicates a failure or malfunction of* the k^{th} type in the j^{th} element and $B_{ijk} = 0$ if the table indicates that such a failure or malfunction did not occur. The function $\prod_{j=1}^{J_i}$ is used to indicate the product of J_i factors in the equation and $\prod_{k=1}^{K_{ij}}$ means the product of K_j factors in the equation (Appendix C).

The expected delay for the m^{th} combination of element states is evaluated by the algorithm:

$$EDLY_m = \sum_{j=1}^{J_i} \sum_{k=1}^{K_{ij}} B_{ijk} EDLY_{ijk} \tag{B-12}$$

It is seen that the only delay considered is that associated with failure or malfunction states which the table indicates have occurred in the m^{th} combination.

Now to provide for the possibility that the time required to restore the system after the occurrence of multiple failures or malfunctions may not be as great as the sum of the individual MRT values, a factor ranging from 0 to 1 is supplied by the analyst and taken into account in restore time calculations. This overlap factor, x, is applied so that the resultant value of MRT_m will range from the maximum of the pertinent MRT_{ijk} values to the sum of these values. The actual algorithm employed is:

$$MRT_m = MAX(MRT_{ijk}) \Big|_{k=1}^{K_{ij}} \Big|_{j=1}^{J_i} + X \cdot \left[\left(\sum_{j=1}^{J_i} \sum_{k=1}^{K_{ij}} B_{ijk} \; MRT_{ijk} \right) - MAX(MRT_{ijk}) \Big|_{k=1}^{K_{ij}} \Big|_{j=1}^{J_i} \right] \tag{B-13}$$

This value is transformed into an <u>expected restore time</u> by multiplying it by the undependability:

$$ERT_m = UD_m \cdot MRT_m \tag{B-14}$$

If s denotes the assembly state assigned by the analyst as the consequence of the occurrence of the $m^{\underline{th}}$ combination of elements states, then the values of UA_m, UR_m, UD_m, $EDLY_m$ and ERT_m determined as above are summed into the corresponding registers for the $s^{\underline{th}}$ assembly state. When all of the M combinations of states have been considered, the computer registers designated for normal operation will contain values for availability, reliability, and dependability of the assembly while registers designated for failure or malfunction states will contain the values of unavailability, unreliability and undependability. At this time, the values for <u>average</u> delay and mean restore time are evaluated for each assembly state as follows:

$$DLY_s = EDLY_s / UD_s \tag{B-15}$$

and

$$MRT_s = ERT_s / UD_s \tag{B-16}$$

Combined values of these parameters for the i^{th} assembly are evaluated by:

$$DLY_i = \left(\sum_{s=1}^{S} EDLY_s \right) / (1-D_i) \tag{B-17}$$

and

$$MRT_i = \left(\sum_{s=1}^{S} ERT_s \right) / (1-D_i) \tag{B-18}$$

where D_i is the probability of normal operation of the i^{th} assembly for the entire functional cycle (mission); that is, the dependability.

A value of average time between occurrences of malfuncitons, ATBO, is derived from the values of use time, T_i, and the dependability calculated for each state of the assembly. For this calculation the Poisson distribution is assumed to hold so that for the j^{th} state of the i^{th} assembly:

$$ATBO_{ij} = \frac{-T_i}{\log_e (D_{ij})} \tag{B-19}$$

This value should be used with caution since the time distribution of malfuctions for higher level assemblies may differ from Poisson. However, the expression of reliability in terms of an average (or expected) time between failures is a familiar practice and the ATBO values are computed to satisfy this need.

APPENDIX C

TABULAR SYSTEM ANALYSIS

THE TASRA CONCEPT

The TASRA mathematical theory is based on the state variables approach and the MARKOV chain model, as discussed by Blazek, Easterday and others [5]. In the state of variables approach, a system or component is considered to be in some state (i.e., operating correctly, degraded or failed). If the component is initially in a good operating state, it will change to another state after a period of operation which can mean it has gone into a failed or degraded state. As an example, consider the use of two components, one with a failed state a'bc and the other with a failed state ab'c and a degraded state abc'. The possible combination of eight states and their transitions is shown in Figure C-1. In TASRA, this same concept is used. To ease the understanding of the multitude of possible combinations of states, the system, its subassemblies and its components are handled through the use of block diagrams and combinatorial tables called TASRA/TASA Tables (See example in Table C-2.) As stated before, the design/reliability engineer/analyst may work with signal flow diagrams or functional block diagrams with which he already is accustomed. Let us first convert Figure C-1 to a block diagram, which may be represented as shown in Figure C-2, where a, b, and c combinations represent the components' states. The combinations of component states are handled on the TASRA/TASA tables.

The Tabular Work Sheets, Tables C-1 and C-2, are used as aids

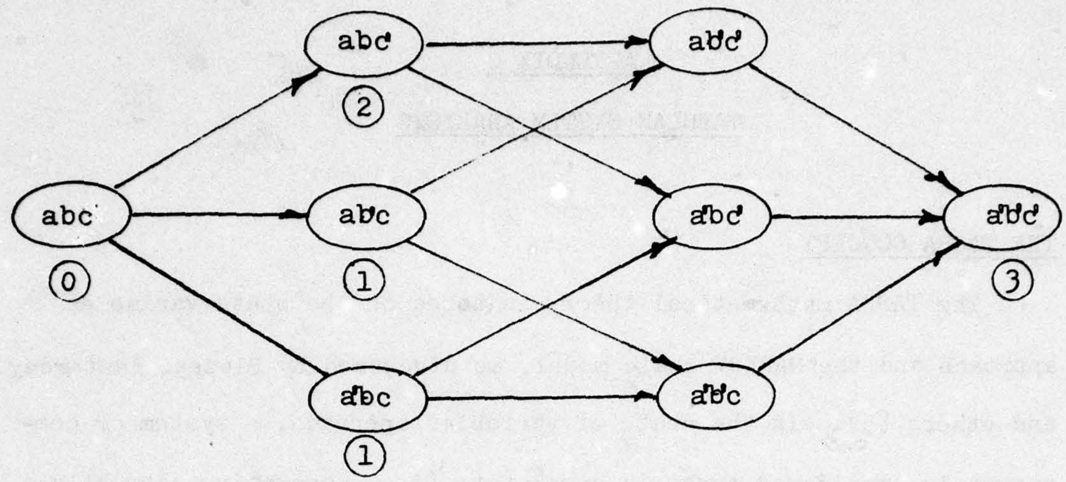

Figure C-1 STATE DIAGRAM FOR ASSEMBLY 104

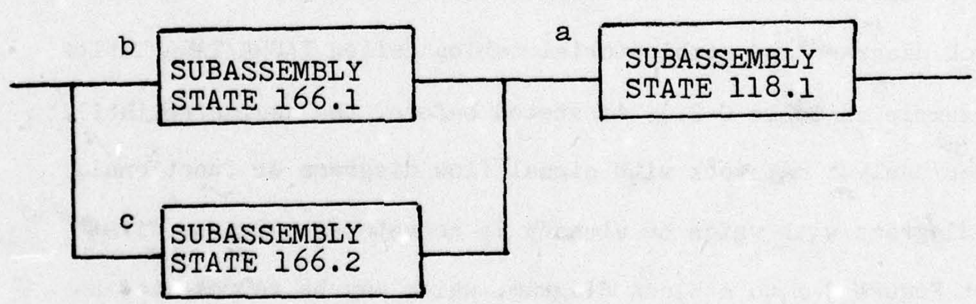

Figure C-2 Block Diagram for ASSEMBLY 104

TABLE C-1 STATE IDENTIFICATION WORK SHEET EXAMPLE

Assy. Nr.	STATE IDENTIFICATION
104.0	Ka-Band MODEM Group (System Initialization)
104.1	Unable to Start System
104.2	Alternate Initialization MODE Required
.3	
.4	
.5	
.6	
.7	
.8	

Col	Input Assy.	STATE IDENTIFICATION
1	118.1	Paper Tape Reader Malfunction
2	166.1	Unable to Load Master Clock
3	166.2	Alternate Initialization MODE Required
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

USED IN ASSEMBLIES:

TASA	Number
209	Ka-Band SATCOM Set (System Initialization)

USES ASSEMBLIES:

TASA	Number
118	Paper Tape Reader
166	Signal Processing (Initialization)

TABLE C-2 TASRA/TASA TABLE WORK SHEET

EXAMPLE

													118 .1 a	166 .1 b	.2 c	104		Card Column	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2		2	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1		3	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	9		4	(2)
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1		5	
0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1		6	
0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1		7	
0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	9		8	(3)
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0			9	
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1			10	
0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0			11	
0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1			12	
0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0			13	
0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1			14	
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0			15	
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0			16	
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1			17	
0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0			18	
0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1			19	
0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0			20	
0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1			21	
0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0			22	
0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0			23	
0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1			24	
0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0			25	
0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0			26	
																		74 - 78	

to guide the analyst in considering the effects of the various combinations of component states as shown in the state diagram, Figure C-2. The tables are simple in concept, easy to follow, standardized for all applications, and do not have any of the complexity involved in developing states diagrams. That complex effort is borne by the computer, not the analyst. Further discussion of the TASRA/TASA Tables would require discussing the details of the procedure, which is not intended in this report.

To obtain a reliability expression, the state variables diagrams may be converted to perform a reliability analysis through the use of the Markov process. The Markov model is based on the probability of a component making the transition from one state to another. Thus, we have introduced probabilities and are on the way to resolving the mean time to failure. Since a component is required to be in one state or another at any time, the Markov process may be described as a discrete-state continuous-time model. Therefore, if we are interested in a particular system failure state (a discrete state) we may calculate the probability of occurrence of this discrete state occuring at any desired time. Since the probability of occurrence of this discrete state is not a constant over time, there is a rate of change of this probability over an increment of time. Thus, the equations describing the probability of occurrence are differential equations. For a system's analysis, there are a series of differential equations which are handled totally by the TASRA which only addresses reliability, whereas TASA includes means to consider availability and dependability based on known MTTR values for the elements under analysis (See Equations B-11a, B-11b, and B-11c in Appendix B).

TASRA/TASA WORK SHEETS (Example, Table C-2)

Preprinted tables of up to 28 pages of 25 lines per page are a shorthand representation of the TASA model for each system assembly. Each line (or row) represents a term in the TASA model for an assembly functional state. These tables are essentially a binary count, with the restriction that only rows containing three "l's" or less are included. The analysis proceeds by assigning input subassembly states to columns of the table working from right to left. A "1" appearing in a column signifies the occurrence of the malfunction or failure state of the input subassembly or element which that column represents. The engineering analysis proceeds by determining for each row of the table the consequences of the combination of input malfunction or failure states denoted by the "l's" appearing in that row in terms of the functional states defined for the assembly. During this analysis it is frequently necessary to assign the consequential assembly functional state for simultaneous input malfunction and failure states on a dominance basis; that is, one input malfunction or failure state produces consequences that dominate over the effect of other simultaneously occuring states.

At the basic level, each column of the TASA table represents an an element malfunction or failure state that has known probability of occurrence. A "1" appearing in this column signifies the occurrence of that malfunction or failure state while a "0" signifies that the state has not occurred. Thus, there is a "probability of non-occurrence" associated with each "0". By multiplying the probabilities associated with each of the "l's" and "0's" in a row, one term is obtained

of the "ility" equation for the assembly function state assigned to that row by the analyst. The sum of the terms for all rows assigned to a particular assembly functional state is an "ility" model for that state. There is a corresponding model for each malfunction and failure state for each assembly throughout the system hierarchy. Note the summary of rules in Figure C-3 and the mathematical model in Figure C-4 (References 5 and 13).

An application of the TASA analysis tool is illustrated in the following example. Let Assembly 104 consist of functional subassemblies 118.1, 166.1 and 166.2. The Assembly, and each subassembly, has mutually exclusive functional states; normal, degraded and inoperative. Whenever Subassembly 166.1 is inoperative, Assembly 104 will also be inoperative. However, INPUT Subassembly state 166.1 and Subassembly state 166.2 in TABLE C-1 are parallel so that Assembly 104 will continue to operate (although in a degraded mode) as long as Subassembly 118.1 and subassembly 166.1 are operational. The functional hierarchy for this example is shown in Figure C-2. For this simple example, the list of possible functional states is included in each block. A number of the possible combinations of states are listed in Table C-1.

The TASA work sheet for this example is shown in Table C-2 [14]. First note that consequence state "9" is reserved for identifying impossible combinations of subassembly states. Since it is required that the functional state definitions be mutually exclusive, it is impossible for one subassembly to be in both the degraded (not failed) state and the failed state. When the TASA work sheet directs consideration of such a state combination, the impossibility is indicated by entering "9"

* FOR EACH ZERO IN THE TASA TABLE FOR A SUBASSEMBLY SUBSTITUTE THE PROBABILITY OF NORMAL OPERATION AT TIME t

* FOR EACH ONE IN THE TASA TABLE FOR A SUBASSEMBLY SUBSTITUTE THE PROBABILITY THAT THE SUBASSEMBLY IS INOPERABLE AT TIME t

* MULTIPLY THE PROBABILITIES IN EACH ROW OF THE TASA TABLE

* SUM THE PROBABILITY PRODUCTS FOR EACH ROW IN THE TASA TABLE ASSIGNED A GIVEN ASSEMBLY STATE NUMBER IN THE ANALYSIS

Figure C-3 SUMMARY OF RULES FOR COMBINING FUNCTIONAL STATE PROBABILITIES

$P_0 = (1-P_a)(1-P_b)(1-P_c)$ NORMAL OPERATION

$P_1 = (1-P_a)P_b(1-Pc)+P_a(1-P_b)(1-P_c)+ P_a(1-P_b)P_c+P_aP_b(1-P_C)$ INOPERABLE

$P_2 = (1-P_a)(1-P_b)P_c$ DEGRADED

$P_3 = 1-(P_0+P_1+P_2)$ OTHER MODES

WHERE: P_a, P_b, P_c = Probability of Inoperative state for Subassembly a, b, c.

P_1 = Probability that the assembly is in an inoperative state as a result of no more than three simultaneous subassembly failures.

P_2 = Probability that the assembly is in a degraded operational state.

P_3 = Probability of simultaneous failures of more than three subassemblies.

P_0 = Probability of normal operation of assembly.

Figure C-4 STATE VARIABLE MATHEMATICAL MODEL FOR EXAMPLE ASSEMBLY

as a consequence state.

The complete documentation (Figure C-5) of each of the engineering decisions pertaining to the consequences of a given combination of subassembly malfunction or failure states is an important benefit of TASA. The DEPEND program provides for an optional reproduction of the TASA work sheets. This documentation makes detailed review of the analysis by other engineering personnel practical. This is particularly beneficial where problems have been detected by the analysis. The detailed engineering review of the analysis can provide significant insight concerning possible causes of the problem and potential technical solutions.

STATE ASSIGNMENTS

EXAMPLE

FOR ASSEMBLY NUMBER 104

KA-BAND MODEM GROUP (SYSTEM INITIALIZATION)

104.1	UNABLE TO START SYSTEM	KA-BAND MODEM
104.2	ALTERNATE INITIALIZATION MODE REQUIRED	KA-BAND MODEM

ASSEMBLY 104 IS USED BY ASSEMBLY(S) 209

SUBASSEMBLY STATE IDENTIFICATION

LABEL	IDENTIFICATION	
119.1	ENT PAPER-TAPE READER MALFUNCTION	
166.1	CMP UNABLE TO LOAD MASTER CLOCK	K-SIG PROC
166.2	CMP ALTERNATE INITIALIZATION MODE REQUIRED	K-SIG PROC

SUBASSEMBLY STATES

a 119.1	b 166.1	c 166.2	104
0	0	0	0
0	0	1	2
0	1	0	1
0	1	1	9
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	9

NOTE: 0 = P of Normal Operation
1 = P of Inoperable Time t
* Mult. P's in a Row
* Sum Row Products of P's

For the Assembly States
0 = operable
1 = inoperable
2 = degraded
9 = impossible state

Figure C-5 Example Assembly to Subassembly State Assignment Demonstration

APPENDIX D

SENSITIVITY CALCULATIONS

INTRODUCTION

The TASA/DEPEND Program, developed by Battelle and reported in AFAL-TR-78-135, Part III, provides subassembly to assembly percentage contribution in the form of DEPEND Sensitivity Calculations in the data set tables attached to this Appendix [14]. The results are presented in terms of the percentage contribution of each element or subassembly state to the unavailability, unreliability and undependability for each defined assembly state. Thus, from these tabulations the relative importance of each element or subassembly state to the malfunction or failure of the assembly can be determined. This provides a rational basis for allocating resources to achieve assembly improvement. Also, it gives a basis for specifying "ility" requirements for elements or subassemblies to assure that the assembly meets its "ility" goals.

TRACING SYSTEM SENSITIVITY

The assembly sensitivity tabulations provided by the DEPEND Program results are used in a top-down chain calculation that proceeds from the first step of establishing a maximum contribution Flow Diagram, as shown in Figure D-1, to the next step of using the calculation procedures given in Table D-1.

Because of the large number of possible paths involved in tracing the percentage contribution to system undependability, unreliability and unavailability, only significant percentage contributions of component to system "ilities" should be addressed. As shown in Figure D-1, only the significant assembly state contributions are given. The DEPEND Sensi-

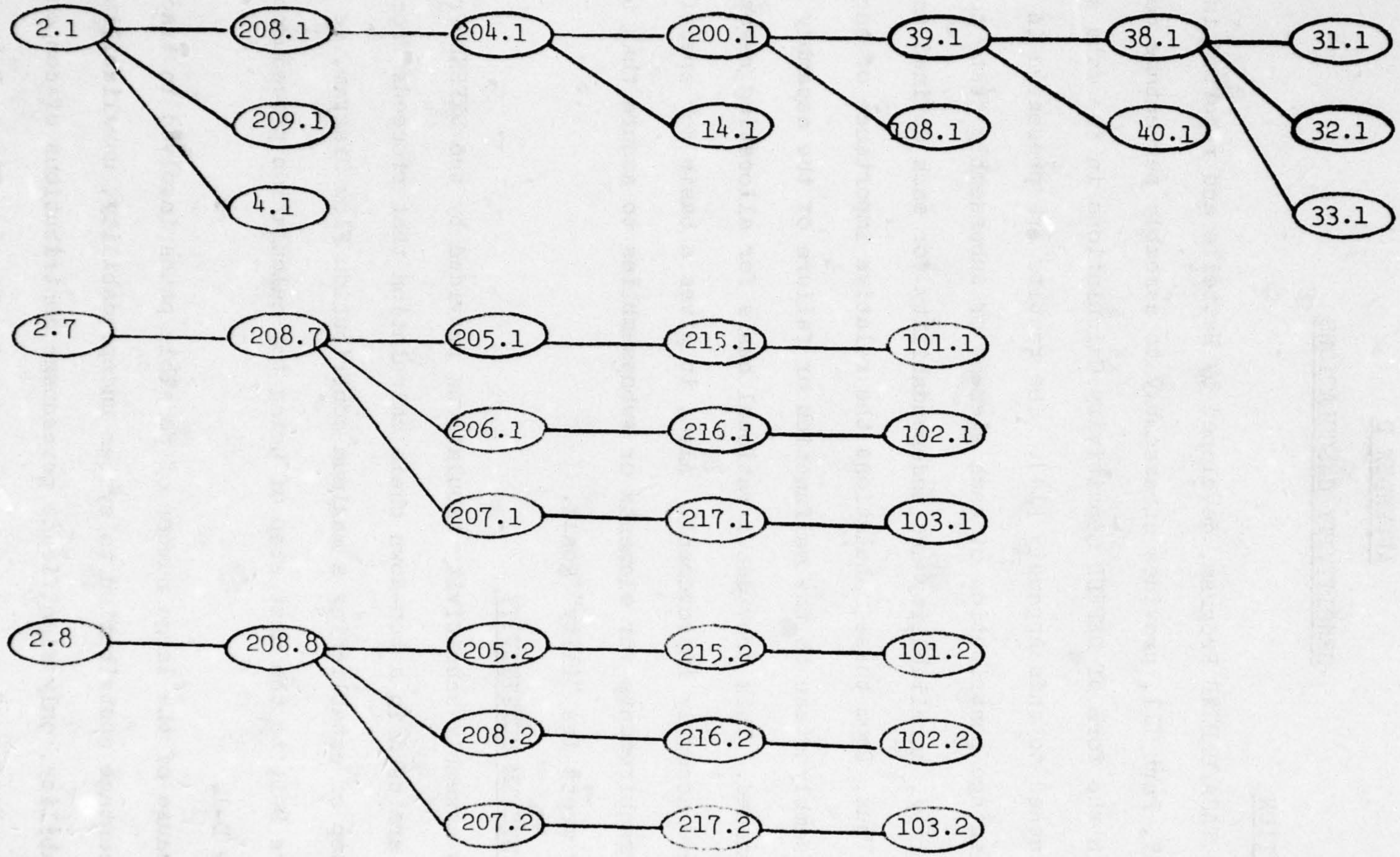

Figure D-1 Maximum Contribution Flow Diagram For TASA Nr. 2 Unavailability

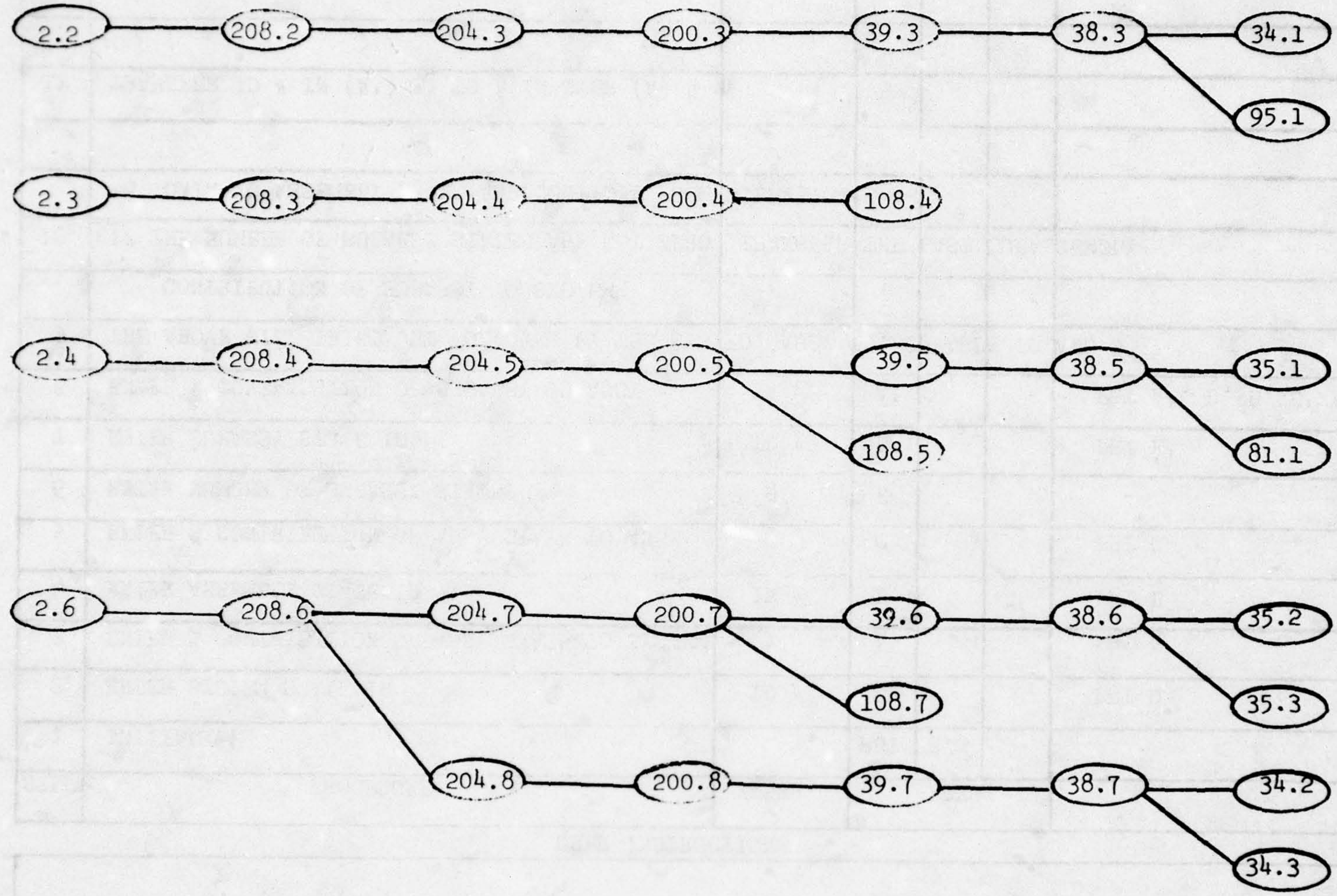

Figure D-1. (Continued)

TABLE D-1 Percentage Contribution of Subassembly to TOTAL SYSTEM Computation -

Program Coding for the TI-58 Programmable Calculator and PC-100A Printer

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			
1	INITIALIZE		RST	R/S		
2	ENTER SYSTEM STATE ID	ID #	D			PRT D
3	ENTER % CONTRIBUTION OF ASSY STATE TO SYSTEM	%	A			PRT A
4	ENTER ASSEMBLY STATE ID	ID #	B			PRT B
5	ENTER % CONTRIBUTION OF ASSY STATE TO ASSY	%	C			PRT C
6	ENTER NUMBER OF SUBASSY STATES	N	E			-
7	ENTER SUBASSY STATE ID	ID #	E'			PRT E'
8	ENTER % CONTRIBUTION OF SUBASSY TO ASSY	%	A'			PRT A', D, B, E' %
9	THE ABOVE WILL PRINT OUT FOLLOWED BY THE SYS ID, ASSY ID, SUBASSY ID AND %					
	CONTRIBUTION OF SUBASSY TO SYSTEM					
10	IF THE NUMBER OF SUBASSY STATES ARE NOT ZERO. TRANSFER THE LAST SUBASSEMBLY					
	DATA TO ASSEMBLY LEVEL AND CONTINUE FROM STEP 3.					
			A			
11	TRANSFER ID # IN (A') E' TO B IN STEP (A) 4		B			

TABLE D-1 (CONTINUED) CODE LISTING

LOC	CODE	KEY
000	29	CP
001	47	CMS
002	58	FIX
003	01	01
004	91	R/S
005	76	LBL
006	14	D
007	42	STO
008	01	01
009	99	PRT
010	91	R/S
011	76	LBL
012	12	B
013	99	PRT
014	42	STO
015	02	02
016	91	R/S
017	76	LBL
018	11	A
019	99	PRT
020	42	STO
021	03	03
022	42	STO
023	04	04
024	43	RCL
025	02	02
026	91	R/S
027	76	LBL
028	13	C
029	99	PRT
030	35	1/X
031	49	PRD
032	04	04
033	25	CLR
034	91	R/S

LOO	CODE	KEY
035	76	LBL
036	15	E
037	22	INV
038	67	EQ
039	00	00
040	56	56
041	43	RCL
042	03	03
043	42	STO
044	06	06
045	00	0
046	42	STO
047	05	05
048	71	SBR
049	00	00
050	96	96
051	43	RCL
052	01	01
053	61	GTO
054	00	00
055	10	10
056	42	STO
057	00	00
058	71	SBR
059	00	00
060	76	76

LOC	CODE	KEY
061	97	DSZ
062	00	00
063	00	00
064	58	58
065	43	RCL
066	05	05
067	42	STO
068	02	02
069	43	RCL
070	06	06
071	42	STO
072	03	03
073	61	GTO
074	00	00
075	22	22
076	43	RCL
077	04	04
078	42	STO
079	06	06
080	43	RCL
081	02	02
082	66	PAU
083	25	CLR
084	91	R/S

LOC	CODE	KEY
085	76	LBL
086	10	E'
087	99	PRT
088	42	STO
089	05	05
090	91	R/S
091	76	LBL
092	16	A'
093	99	PRT
094	49	PRD
095	06	06
096	98	ADV
097	43	RCL
098	01	01
099	99	PRT
100	43	RCL
101	02	02
102	99	PRT
103	43	RCL
104	05	05
105	99	PRT
106	43	RCL
107	06	06
108	99	PRT
109	98	ADV
110	92	RTN
111	00	0

INPUT

2.1
24.8
208.1
24.3
204.1
22.8

OUTPUT

2.1
208.1
204.1
23.3

tivity Tabulation for a particular assembly shows many low or zero percentage subassembly state to assembly state paths. These are ignored.

A calculation procedure was developed using the TI-58 Programmable Calculator and the PC-100A Printer [31]. Table D-1 presents the user instruction and its program code listing. As illustrated in Table D-2, this procedure will provide a means to calculate the percentage contribution one step at a time from the System State 2.1 to the Assembly State 208.1, to finally the Subassembly State 31.1, with a contribution of 1.8% for example. Thus, a top-down calculation is accomplished in the following manner: Referring to Table D-2, 34.5% of the system (TASA Nr. 2) unavailability is contributed by State 2.1, and 24.8% is contributed by Assembly State 208.1. From Table D-2 it is seen that Subassembly 204.1 is responsible for 22.8% of Assembly 208 contribution, and 24.3% of Assembly 208 is attributed to Assembly State 208.1. Therefore, (22.8/24.3) x 24.8% = 23.3% contribution to the total system by Subassembly 204.1.

This process is continued by referring to the sensitivity tabulation and the Maximum Contribution Flow Diagram and so on down through the functional hierarchy. The results obtained by tracing all significant paths may be tabulated to identify and rank the least dependable, reliable or available system element.

Tables Nr. D-3, D-4 and D-5 are tabulations of the most significant contributors for the system under study. The percentage contribution of assemblies to systems was calculated for the un-ilities, Table D-3 - Unavailability, Table D-4 - Unreliability, and Table D-5 - Undependability. System States 2.1 and 2.6 were selected to illustrate the use of this

TABLE D-2. ILLUSTRATION - PERCENTAGE CONTRIBUTION OF SUBASSEMBLY TO TOTAL SYSTEM UNAVAILABILITY USING TI-58 CALCULATOR PRINTOUT

% ASSY STATE TO SYS	A	24.8	23.3	23.3	17.3	17.3	14.4	14.4	8.1	8.1	8.1
ASSY ID NR.	B	208.1	204.1	204.1	200.1	200.1	39.1	39.1	38.1	38.1	38.1
% ASSY STATE TO ASSY	C	24.3	34.7	34.7	28.3	28.3	29.6	29.6	19.3	19.3	19.3
SUBASSY ID NR.	E'	204.1	14.1	200.1	108.1	39.1	40.1	38.1	31.1	32.1	33.1
% SUBASSY TO ASSY	A'	22.8	8.8	25.7	4.6	23.6	12.8	16.6	4.2	7.8	7.2
SYS ID NR.	D	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
ASSY ID NR.	B	208.1	204.1	204.1	200.1	200.1	39.1	39.1	38.1	38.1	38.1
SUBASSY ID NR.		204.1	14.1	200.1	108.1	39.1	40.1	38.1	31.1	32.1	33.1
% CONTRIBUTION TO TOTAL SYS.		23.3	5.9	17.3	2.8	14.4	6.2	8.1	1.8	3.3	3.0

TABLE Nr. D-3 PERCENTAGE CONTRIBUTION SUBASSEMBLY TO SYSTEM RUN ONE

X UNAVAILABILITY ___ UNRELIABILITY ___ UNDEPENDABILITY

% Assy State-Sys A	Assy ID B	% Assy State C	Sys ID D	Number of Subassy E	Subassy ID E'	%Subassy State A'	%Subassy to Sys
2.9	E 4.1	2.9	2.1	0	-	-	2.9
6.6	E209.1	6.6		0	-	-	6.6
24.8	208.1	24.3		1	204.1	22.8	23.3
23.3	204.1	34.7		1	E 14.1	8.7	5.8
23.3	204.1	34.7		1	200.1	25.7	17.3
17.3	200.1	28.3		1	E 108.1	4.6	2.8
17.3	200.1	28.3		1	39.1	23.6	14.4
14.4	39.1	29.6		1	E 40.1	12.8	6.2
14.4	39.1	29.6		1	38.1	16.6	8.1
8.1	38.1	19.3		1	E 31.1	4.2	1.8
8.1	38.1	19.3		1	E 32.1	7.8	3.3
8.1	38.1	19.3		1	E 33.1	7.2	3.0
24.9	208.6	12.7	2.6	1	204.7	10.9	21.4
21.4	204.7	33.5		1	200.7	33.4	21.3
21.3	200.7	36.7		1	39.6	28.1	16.1
16.1	39.6	35.2		1	38.6	35.1	16.1
16.1	38.6	40.5		1	E 35.2	35.0	13.9
16.1	38.6	40.5		1	E 35.3	5.8	2.3
21.3	200.7	36.7		1	E 108.7	8.8	5.1
24.9	208.6	12.7		1	204.8	1.1	2.2
2.2	204.8	2.4		1	200.8	1.4	1.3
1.3	200.8	1.5		1	39.7	1.3	1.1
1.1	39.7	1.6		1	38.7	1.6	1.1
1.1	38.7	1.9		1	E 34.2	1.5	1.9
1.1	38.7	1.9		1	E 34.3	0.3	0.2

TABLE Nr. D-4		PERCENTAGE CONTRIBUTION SUBASSEMBLY TO SYSTEM			RUN ONE		
	___ UNAVAILABILITY	X UNRELIABILITY		___ UNDEPENDABILITY			
% Assy State-Sys A	Assy ID B	% Assy State C	Sys ID D	Number of Subassy E	Subassy ID E'	%Subassy State A'	%Subassy to Sys
4.7	E 4.1	4.7	2.1	0	-	-	4.7
0.2	E 209.1	0.2		0	-	-	0.2
31.6	208.1	40.6		1	204.1	39.2	30.5
30.5	204.1	45.6		1	E 14.1	12.0	8.0
30.5	204.1	45.6		1	200.1	33.6	22.5
22.5	200.1	37.7		1	E 108.1	12.8	7.6
22.5	200.1	37.7		1	39.1	25.0	14.9
14.9	39.1	39.7		1	E 40.1	13.0	4.9
14.9	39.1	39.7		1	38.1	26.7	10.0
10.0	38.1	30.7		1	E 31.1	7.4	2.4
10.0	38.1	30.7		1	E 32.1	6.4	2.1
10.1	38.1	30.7		1	E 33.1	16.9	5.5
10.9	208.6	15.1	2.6	1	204.7	12.7	9.2
9.2	204.7	15.7		1	200.7	15.7	9.2
9.2	200.7	18.2		1	39.6	12.1	6.1
6.1	39.6	19.7		1	38.6	19.7	6.1
6.1	38.6	22.9		1	E 35.2	18.1	4.8
6.1	38.6	22.9		1	E 35.3	4.8	1.3
9.2	200.7	18.2		1	E 108.7	6.1	3.1
10.9	208.6	15.1		1	204.8	2.0	1.4
1.4	204.8	2.4		1	200.8	2.4	1.4
1.4	200.8	2.8		1	39.7	2.1	1.1
1.1	39.7	3.4		1	38.7	3.4	1.1
1.1	38.7	3.9		1	E 34.2	2.7	0.9
1.1	38.7	3.9		1	E 34.3	1.2	0.3

TABLE Nr. D-5 PERCENTAGE CONTRIBUTION SUBASSEMBLY TO SYSTEM RUN ONE

___ UNAVAILABILITY ___ UNRELIABILITY X UNDEPENDABILITY

% Assy State-Sys A	Assy ID B	% Assy State C	Sys ID D	Number of Subassy E	Subassy ID E'	%Subassy State A'	%Subassy to Sys
4.5	E 4.1	4.5	2.1	0	-	-	4.5
1.1	E 209.1	1.1		0	-	-	1.1
30.4	208.1	33.0		1	204.1	29.5	27.2
27.2	204.1	34.7		1	E 14.1	8.8	6.8
27.2	204.1	34.7		1	200.1	25.8	20.2
20.2	200.1	28.3		1	E 108.1	4.6	3.2
20.2	200.1	28.3		1	39.1	23.6	16.8
16.8	39.1	29.6		1	40.1	12.8	7.2
16.8	39.1	29.6		1	38.1	16.6	9.4
9.4	38.1	19.3		1	E 31.1	4.2	1.9
9.4	38.1	19.3		1	E 32.1	7.8	3.7
9.4	38.1	19.3		1	E 33.1	7.2	3.4
12.6	208.6	13.6	2.6	1	204.7	11.1	10.4
10.4	204.7	33.5		1	200.7	33.4	10.3
10.3	200.7	36.7		1	39.6	28.6	7.9
7.9	39.6	35.1		1	38.6	35.7	7.9
7.9	38.6	40.5		1	E 35.2	35.0	6.8
7.9	38.6	40.5		1	E 35.3	5.4	1.1
10.3	200.7	36.7		1	E 108.7	8.6	2.2
12.7	208.6	13.6		1	204.8	1.5	1.4
1.4	204.8	1.4		1	200.8	1.4	1.4
1.4	200.8	1.5		1	39.7	1.3	1.2
1.2	39.7	1.6		1	38.7	1.6	1.2
1.2	38.7	1.9		1	E 34.2	1.5	1.8
1.2	38.7	1.9		1	E 34.3	0.3	0.2

calculator procedure and to compare the differences in element to system percentage contribution for each element "ility." For example, the percentage contribution of Element 35.2 for Unavailability is 13.9%, for Unreliability is 4.8%, and for Undependability is 6.8%. Thus, the percentage contribution as a criterion should be carefully considered in terms of realistic applications. The differences would also indicate whether reliability or maintainability should be the driving factor.

Ka-Band SATCOM SET PERCENTAGE CONTRIBUTION

Ka-Band SATCOM SET Model percentage contribution tabulations for RUN ONE are given in Table D-6. These are the bottom line percentage contribution values for each element of the Ka-Band SATCOM SET, TASA Nr. 2 - RUN ONE. As discussed in Section III, the greatest contributor appears to be the High Power Amplifier (TASA Nr. 35-81). However, when RUNS FIVE, SEVEN and EIGHT were evaluated, the percentage contribution of this element was reduced. These findings are discussed in Section III.

TABLE D-6 TASA Nr. 2 Ka-Band System Functions RUN ONE
Percentage Contribution to Unavailability, Unreliability and Undependability

TASA Nr.	%UAV	%URE	%UDE	TASA Nr	%UAV	%URE	%UDE
2.1	-	-	-	2.6	-	-	-
4.1	2.9	4.7	4.5	35.2	13.9	4.8	6.8
209.1	6.6	0.2	1.1	35.3	2.1	0.7	1.0
14.1	5.6	8.0	6.8	34.2	1.5	1.0	1.8
108.1	2.8	7.6	3.2	34.3	0.3	0.8	0.2
40.1	6.2	4.9	7.2	108.7	5.1	2.7	2.2
31.1	1.8	2.4	1.9				
32.1	3.3	2.1	3.7	2.7	-	-	-
33.1	3.0	5.5	3.4	101.1	3.4	3.1	3.9
				102.1	1.8	4.2	2.9
2.2	-	-	-	103.1	1.2	3.1	4.0
34.1	2.1	3.5	2.6				
95.1	1.5	1.2	2.0	2.8	-	-	-
				101.2	1.3	2.9	2.8
2.3	-	-	-	102.2	6.5	5.8	6.9
108.4	0.7	2.5	1.8	103.2	5.0	5.8	5.2
2.4	-	-	-				
35.1	3.4	4.4	2.3				
81.1	9.2	3.8	7.3				
108.5	2.9	7.6	2.4				

APPENDIX E

RELIABILITY-AVAILABILITY MINIMUM COST DECISION MODEL

INTRODUCTION

An optimum economic system reliability or availability, which is the degree of reliability and/or maintainability at a minimum cost is difficult to realize in practice. This is because estimating the variations in manufacturing, design and maintenance costs is very complex for a given reliability or availability.

The first step in any optimization procedure should be an examination of the various alternatives for possible trade-offs between the cost of system reliability and maintainability design and the cost of system maintenance during a fixed period of time. Thus, total system cost may be reduced without impacting effectiveness by adjusting the balance between cost of design for reliability and maintainability and cost of maintenance.

MINIMUM COST DECISION MODEL FORMULATION

Fabrycky and Thuesen, in Chapter 14 of their text entitled "Economic Decision Analysis", addresses a basic approach for a minimum cost decision model [15]. This approach was applied to the formulation of the Ka-Band SATCOM SET Reliability/Availability Minimum Cost Decision Model as described in this Appendix.

When the total cost of a particular alternative is a function of an increasing system availability cost component and a decreasing

system maintenance cost component, the following mathematical model applies:

$$TC = AX^{n} + B/X + C$$

where:

TC = total cost of activity,

n = exponent of X describing the cost to MTBF ratio,

X = a common decision variable,

A, B, and C are a constant. (See Figure E-1)

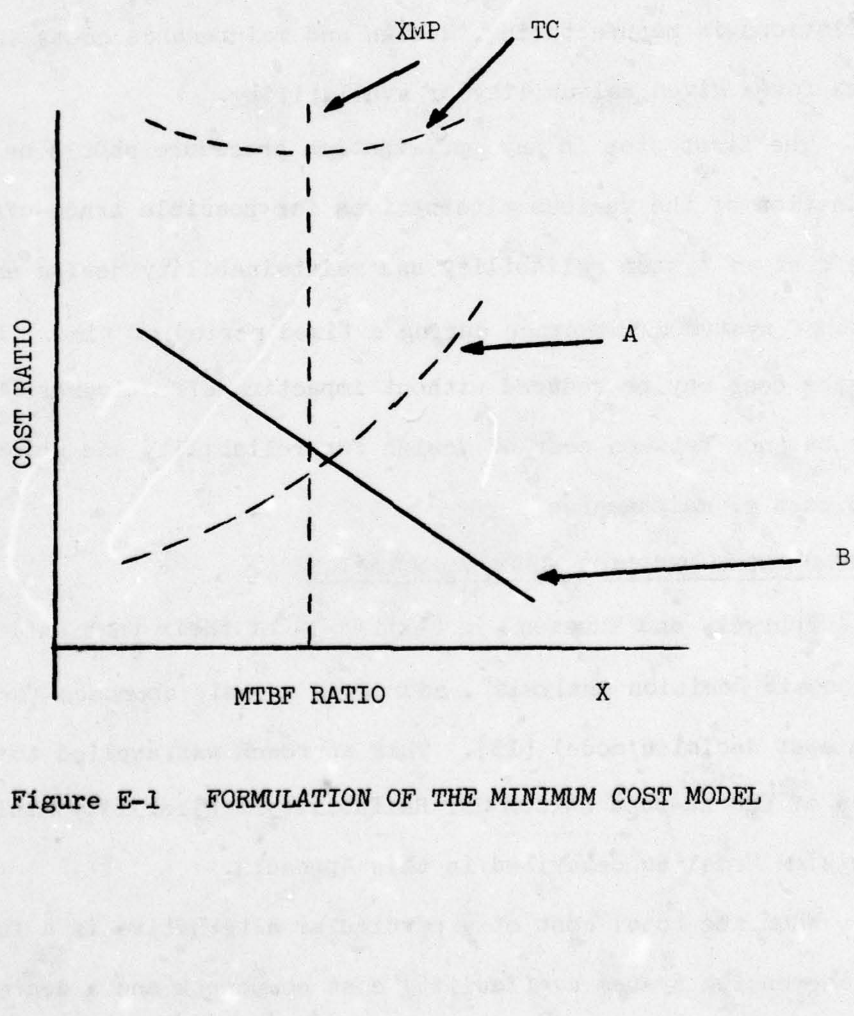

Figure E-1 FORMULATION OF THE MINIMUM COST MODEL

The total cost is a measure of effectiveness. The variable under direct control of the decision maker is X, whereas the constants A, B, and C are not under their direct control. The objective is to determine the ratio of X which will result in a minimum cost in terms of the cost for the design of system reliability (AX^n) and the cost of maintenance (B/X).

A direct approach was used to determine the minimum cost, using differential calculus. This involves taking the derivative of TC with respect to X, equating the result to zero and solving for X. For the model formulated this is:

$$\frac{dTC}{dX} = nAX^{n+1} - \frac{+B}{X^2} = 0$$

$$X = \sqrt[(n+1)]{\frac{B}{nA}}$$

The value of X found by this means will be a minimum and is designated the minimum cost point (XMP).

ASSUMPTIONS

a. MTBF = 328 hours, based on findings by Battelle in a recently completed study [14].

b. System operated for ten years.

c. Interest rate of 9%.

d. Base hypothetical acquisition cost $406K.

e. Base hypothetical restoration cost $11K per failure.

f. Let n = 2, an exponent of X, a common decision variable as related to acquisition cost per findings by Battelle using the RCA-PRICE cost model.

g. Each system is operated and maintained for about 5400 hours per year.

CALCULATION PROCEDURES AND PROGRAM CODING

A program was formulated for the TI-58 programmable calculator [31] based on the equations listed in Tables E-1A and E-1B. Note that these tables also present the program coding and the input and output printout.

A demonstration problem was addressed, using the procedures of Table E-1A, entitled, "User's Instruction."

Initialize and Enter Base Line Data

Step 1. Initialize all data registers.

Step 2. Store MTBF hours in register 05 as (MF).

Step 3. Store the value of total acquisition cost for the assembly under study to register 06 as (CB).

Step 4. Store estimated restoration cost per failure for the assembly under study to register 07 as (CF).

Step 5. Store the cost to MTBF ratio power factor "n" to register 16 (n).

Step 6. Enter the number of periods (N) via label A and print N = 10.

Step 7. Enter the interest rate per periods (I) via label B and print I = 9%.

Calculate Present Worth Factor

Step 8. Compute present worth factor (PWF) and print PWF = 6.418 when label C is activated. See Table E-1B equations for PWF.

In Steps 8A, 8B, 8C, and 8D, the base MTBF, total acquisition cost, restoration cost per failure and cost to MTBF power factor values as entered earlier will be printed as MF = 328, CB = 406, CF = 11, and n = 2.0.

TABLE E-1A

MINIMUM COST DECISION MODEL - PROGRAM CODING FOR THE TI-58 PROGRAMMABLE CALCULATOR AND PC-100 A PRINTER

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			
1	INITIALIZE		RST	R/S		0.000
2	ENTER MTBF HOURS	MF	STO	05		
3	ENTER TOTAL ACQUISITION COST	CD	STO	06		
4	ENTER RESTORE COST PER FAILURE	CR	STO	07		
5	ENTER COST RATIO POWER FACTOR	n	STO	16		
6	ENTER NUMBER OF PERIODS	N	lbl	A		prt-N
7	ENTER INTEREST RATE PER PERIOD	I	lbl	B		prt-I
8	COMPUTE PRESENT WORTH FACTOR		lbl	C		prt-PWF
8A	PRINT MTBF HOURS					prt-MF
8B	PRINT TOTAL ACQUISITION COST					prt-CB
8C	PRINT RESTORE COST PER FAILURE					prt-CF
8D	PRINT COST RATIO TO MTBF RATIO POWER FACTOR					prt-n
9	ENTER MTBF RATIO, PRINT Mr	Mr	lbl	D		prt-Mr
9A	PRINT COST RATIO					prt-Cr

TABLE E-1A (CONTINUED) MINIMUM COST

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			
10	COMPUTE TOTAL COST		1bl	E		
10A	TOTAL FAILURES PER YEAR, PRINT					prt-Fyr
10B	TOTAL EQUIV. ANNUAL ACQUISITION COST, PRINT					prt-CR
10C	TOTAL ANNUAL RESTORATION COST, PRINT					prt-CM
10D	TOTAL EQUIVALENT ANNUAL COST, PRINT					prt-CTCEA
11	COMPUTE MTBF RATIO		1bl	2nd	E	
11A	CB/PWF, PRINT					prt-A
11B	CFXFB, PRINT					prt-B
11C	B TO nA RATIO					prt-B/nA
11D	MTBF RATIO FOR MINIMUM COST, PRINT					prt-XMP
12	ENTER MINIMUM COST/MTBF RATIO	XMP	1bl	D		prt-Mr
12A	PRINT MINIMUM/MTBF RATIO					XMP
12B	COMPUTE AND PRINT Fyr		1bl	E		prt-Fyr

TABLE E-1A (CONTINUED) MINIMUM COST

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			
12C	PRINT, CR					prt-CR
12D	PRINT, CM					prt-CM
12E	PRINT MINIMUM COST					prt-C_{TCEA}

TABLE E-1B PROGRAM CODE LISTING MINIMUM COST DECISION MODEL

LOC	CODE	KEY	PROCEDURE STEP		
000	29	CP			
001	47	CMS			
002	58	FIX			
003	03	03			
004	91	R/S	1		INITIALIZE
005	42	STO			
006	05	05	2	(MF)	MTBF-HOURS
007	42	STO			
008	06	06	3	(CR)	Total Development-Acquisition Cost
009	42	STO			
010	07	07	4	(CF)	Restoration Cost per Failure
011	42	STO			
012	16	16	5	(n)	Exponent n for Cost Ratio Power Factor
013	76	LBL			
014	11	A	6	(N)	Number of periods under study
015	42	STO			
016	01	01			
017	99	PRT			Enter Interest Rate per Period
018	92	RTN			
019	76	LBL			
020	12	B	7	Print out	
021	36	PGM			
022	18	18		Input	
023	12	B			
024	99	PRT		10.000 (N)	
025	92	RTN		9.000 (I)	

TABLE E-1B (CONTINUED) CODE LISTING

LOC	CODE	KEY	STEP
026	76	LBL	
027	13	C	8 PRINT (PWF)
028	36	PGM	
029	18	18	
030	18	C'	
031	42	STO	
032	10	10	
033	99	PRT	
034	98	ADV	
035	43	RCL	
036	05	05	
037	99	PRT	8A PRINT PWF (MF)
038	43	RCL	
039	06	06	
040	99	PRT	8B PRINT (CB)
041	43	RCL	
042	07	07	
043	99	PRT	8C PRINT TOTAL ACQUISITION COST (CF)
044	43	RCL	
045	16	16	
046	99	PRT	8D PRINT RESTORATION COST PER FAILURE (n)
047	98	ADV	
048	92	RTN	

$$PWF = (1-(1+i)^{-N})/i$$

$$i = I\%/100$$

6,418

INPUT

328,000

406,000

11,000

2,000

TABLE E-1B (CONTINUED) CODE LISTING

$$\boxed{Cr = Mr^n}$$

LOC	CODE	KEY	STEP	STEP	
049	76	LBL			
050	14	D	9	12	
051	42	STO			
052	03	03			PRINT MTBF RATIO (Mr)
053	99	PRT			
054	45	YX			
055	43	RCL			
056	16	16			
057	95	=	9A	12A	PRINT MINIMUM (Cr)
058	42	STO			
059	04	04			
060	99	PRT	INPUT	1.000	1.127 (XMP)
061	98	ADV	OUTPUT	1.000	1.270
062	91	R/S			

TABLE E-1B (CONTINUED) CODE LISTING

LOC	CODE	KEY	LOC	CODE	KEY
063	76	LBL	096	65	×
064	15	E	097	43	RCL
065	53	(	098	07	07
066	05	5	099	54	)
067	04	4	100	55	÷
068	00	0	101	43	RCL
069	00	0	102	03	03
070	55	÷	103	54	)
071	43	RCL	104	42	STO
072	05	05	105	14	14
073	54	)	106	95	=
074	95	=	107	42	STO
075	42	STO	108	15	15
076	11	11	109	98	ADV
077	53	(	110	43	RCL
078	53	(	111	11	11
079	43	RCL	112	55	÷
080	06	06	113	43	RCL
081	65	×	114	03	03
082	43	RCL	115	95	=
083	04	04	116	42	STO
084	54	)	117	17	17
085	55	÷	118	99	PRT
086	43	RCL	119	43	RCL
087	10	10	120	13	13
088	54	)	121	99	PRT
089	42	STO	122	43	RCL
090	13	13	123	14	14
091	85	+	124	99	PRT
092	53	(	125	43	RCL
093	53	(	126	15	15
094	43	RCL	127	99	PRT
095	11	11	128	98	ADV
			129	91	R/S

STEP	STEP	
10		FB = 5400/MF
10A	12B	Fyr = FB/Mr
10B	12C	CR = (CBxCr)/PWF
10C	12D	CM = (FBxCF)/Mr
10D	12E	C_{TCEA} = CR + CM

OUTPUT	OUTPUT
16.463	14.608
63.263	80.352
181.098	160.690
244.361	241.042

TABLE E-1B (CONTINUED) CODE LISTING

LOC	CODE	KEY	LOC	CODE	KEY
130	76	LBL	154	53	(
131	10	E'	155	43	RCL
132	43	RCL	156	16	16
133	06	06	157	65	×
134	55	÷	158	43	RCL
135	43	RCL	159	18	18
136	10	10	160	54	)
137	95	=	161	54	)
138	42	STD	162	99	PRT
139	18	18	163	22	INV
140	99	PRT	164	45	Y×
141	43	RCL	165	53	(
142	07	07	166	43	RCL
143	65	×	167	16	16
144	43	RCL	168	85	+
145	11	11	169	01	1
146	95	=	170	54	)
147	42	STD	171	95	=
148	19	19	172	42	STD
149	99	PRT	173	20	20
150	53	(	174	99	PRT
151	43	RCL	175	98	ADV
152	19	19	176	91	R/S
153	55	÷	177	00	0

STEP

11

11A — A = CB/PWF

11B — B = CFxFB

11C — B/MA

11D — XMP = (n+1) $\sqrt{B/(nA)}$

Minimum Cost - Ratio

OUTPUT

63.263
181.098
1.431
1.127

Calculate Cost Ratio

Step 9. Select a MTBF ratio (M_r) starting at 1.0 See equation on Table E-1B Print this value $M_r = 1.0$.

Step 9A. Compute (C_r) and print out the cost ratio value. $C_r = 1.0$.

Total Cost Calculation

Step 10. The total cost of the assembly under study is computed when Label E is activated. Note that in Table E-1B the equation for FB at Step 10 will give the number of failures per period. At Step 10A, F_{yr} gives the number of failures per period as related to the MTBF ratio and presented as $F_{yr} = 16.463$. In Step 10B, the annual equivalent acquisition cost is computed and printed as CR = 63,213 and in Step 10C the annual cost of maintenance is computed and printed as CM = 181,098. In Step 10D, the total equivalent annual acquisition cost is computed and printed as $C_{TCEA} = 244{,}361$.

Minimum Cost Calculation

Step 11. Calculate the minimum cost ratio XMP (see equations in Table E-1B, where in Step 11A, A equals the total acquisition cost (CB) divided by the present worth factor (PWF) and printed out as 63,263. In Step 11B, B equals the product of the restoration cost for each failure (CF) times the failures per year (FB) and printed as 181,098. In Step 11C, the ratio of the base line values, B divided by nA wherein n is the exponent of the Cost to MTBF relationship results in a print out of 1.431. Since n = 2, minimum cost ratio (XMP) in Step 11D equals 1.127.

Step 12. At this point, this value of XMP is entered into Step 12 to calculate the minimum cost at the MTBF ratio of XMP, resulting in

F_{yr} failures per year equals 14.608 in Step 12B. In Step 12C, equivalent annual acquisition cost (CR) equals 80,352 dollars. In Step 12D, annual maintenance cost (CM) equals 160,690, the minimum total cost (MC_{TCEA}) equals 241.042 in Step 12E.

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